Comparing value chain GHG emissions in the power and transport sectors for selected technologies

Report – extended study
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This report has been prepared by *Environmental Resources Management (ERM)*.
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1 EXECUTIVE SUMMARY

The European Commission has recently published the EU Long-term Vision for a Climate Neutral Economy in which the European Union (EU) aims to achieve net-zero greenhouse gas (GHG) emissions by 2050, in line with the requirements of the *Paris Agreement*, the need for global emissions to significantly curb and, more broadly, for our economies to substantially decarbonize. As a result, changes are required in all main sectors that make up the EU emissions: power generation, industry, transport, buildings, construction, and agriculture.

This study focuses on the contribution (and the potential for reduction) from the power generation and transport sectors. It is intended to provide an independent and transparent assessment of the greenhouse gas (GHG) emissions in the European Union (EU) and in 5 countries (Italy, Germany, France, Spain and Romania), in the current situation and as projected in 2030 and 2050. **The study covers the entire electricity and gas value chain**, while highlighting the contribution of each phase from exploration and production, to final consumption, using internationally reliable and publicly-available sources.

For this purpose, an innovative methodology has been developed by coupling life-cycle tools with energy transition scenarios by 2030 and 2050, using the European Commission EUCO30 scenario, the IEA 2017 WEO New Policies Scenario (NPS) and 2016 2°C Scenario (2DS) by 2030, and the 2017 WEO NPS and 2016 WEO 2DS scenarios by 2050.[1]

The power sector analysis compares GHG emissions per unit of electricity generated by a CCGT natural gas vs. a coal-fired power plant, following the trends set by the scenarios. **The transport sector analysis compares GHG emissions per kilometre emitted** by an electric vehicle vs. a methane (compressed and liquefied natural gas) vehicle, a diesel vehicle, a petrol vehicle, and a plug-in hybrid vehicle, and uses the outcome of the power sector analysis for the inputs related to power generation in the current situation (2015 ENTSOE power generation data), in 2030 and in 2050. In particular, a hybrid methodology derived from the approach developed by the EU Joint Research Centre (JRC), **combining a well-to-wheel boundary and a life cycle analysis**, is used to estimate the GHG emissions emitted by a vehicle per kilometre.

For the transport sector analysis, the following vehicle data are collected for car segments A, B, and C from the UK Vehicle Certification Agency database: emission factor; fuel consumption / 100 km; carbon monoxide (CO) emissions; total hydrocarbon (THC) emissions; nitrogen oxide (NOx) emissions; Particulates; and Electricity consumption / km, under New European Driving Cycle (NEDC) test conditions. Vehicle weight are from the European Environment Agency database. **For all vehicle data, a weighted average based on**

[1] Scenarios are up to 2040. 2045 and 2050 figures have been obtained by applying the trend set by the scenarios starting from 2040 data. Refer to section 3.1 (pages 9-11) for the definition of the scenarios.

sales values for the 5 most sold car models per segment (A, B, and C)[1] in Europe in 2017 has then been calculated for each vehicle fuel type (petrol, diesel, electricity/petrol, electricity, and natural gas), throughout the analysis. As the manufacturer's data was only available under NEDC test conditions, in order to get emissions under worldwide harmonized vehicle test procedure (WLTP) conditions, a conversion factor from the European Commission Joint Research Centre was applied. Likewise, to compare those with real driving emissions (RDE), a conversion factor from the International Council on Clean Transportation (ICCT) and the Netherlands Organization for applied scientific research (TNO) is used to convert NEDC emissions into RDE.

The results of the assessment are presented in this report, starting from the current situation (2015 ENTSOE power generation data) and then detailing the projected results at 2030 and 2050 following the trends set by the EUCO30, WEO NPS, and WEO 2DS scenarios.
This outline reflects the increasing potential for decarbonization over time, and the significant role that the electrification of the transport sector will play to align with the current commitments and meet the long-term decarbonisation targets, needed to achieve the objectives set out in the *Paris Agreement.*

Current situation

In the baseline year (2015 data), the power analysis shows that specific GHG emissions from coal-fired power plant exceed specific GHG emissions from natural gas power plants. Moreover, overall GHG emissions from coal-fired power plant are higher than the ones from natural gas power plants at the EU level and in the countries analysed, with the exception of France, due to the higher use of natural gas vs. coal-fired power plants. With regard to GHG emissions per unit of electricity generated, the highest CCGT natural gas emission factors are those of Spain and Italy, which may be explained by the fact these countries current gas supply comes from LNG import and countries of supply that have highest natural gas production emission factors. Romania has the highest coal emission factor out of the geographies considered as the main fuel used is lignite with a very low calorific value, as opposed to hard coal, which is predominantly used in the other countries. When considering the overall value chain, both for natural gas and coal-fired power plants, downstream GHG emissions by far exceed upstream & midstream GHG emissions. **Upstream and midstream emissions of CCGT natural gas represent roughly 20% of the overall emissions** (except in Romania, where they are lower due to a less emissive gas supply chain). **In the case of coal, upstream and midstream emissions represent about 10% of the overall emissions** (except in Romania, where they are higher due to an extensive use of more carbon intensive lignite).

The transport analysis for C segment[2] vehicles **shows that, both under worldwide-harmonized vehicle test procedure (WLTP) conditions and in real driving ones, electric vehicles already outperform internal combustion vehicles in all the geographies considered**. Electricity has lower final GHG emissions compared to fossil fuels. Electric vehicles benefit also from a higher tank-to-wheel efficiency in balanced electricity systems

[1] Passenger vehicles are classified by the European Commission into different segments according to their size.

[2] C segment cars are medium cars (small family cars).

compared to internal combustion vehicles. **As of today, an electric vehicle generates on average well-to-wheel + life-cycle GHG emissions of around 30-40% less comparing to internal combustion vehicles.** Analogue results are found when comparing also A and B segments of vehicles.

Projections at 2030 and 2050

At the 2030 time horizon, the power analysis shows contrasted results in terms of the relative importance of GHG emissions from coal-fired power plants vs. natural gas fired power plants, depending on the scenario taken into account. At the EU28 level, when considering the EUCO30 scenario, GHG emissions associated with coal-fired power plants are still exceeding those from natural gas power plants, whereas emissions from coal significantly decrease when considering the WEO NPS Scenario and, even more so, when considering the WEO 2DS Scenario.

This is no longer valid at the 2050 time horizon, when the power analysis shows a significant decrease in GHG emissions for all the scenarios considered. At the EU28 level, no coal-fired plants are projected to be in operation in 2050, thus resulting in zero emissions from coal, whereas emissions from natural gas plants are largely dependent on the scenario considered. This result reflects the different trajectories in terms of power production when considering the broad policy commitments and plans announced by countries as set in the NPS Scenario, and the more substantial transition required to meet the targets set by the 2DS Scenario and needed to meet the objectives of the *Paris Agreement*.

With regard to the emission factors in terms of **GHG emissions per unit of electricity generated from fossil fuels, they are projected to increase in 2050 vs. 2030** in both the NPS Scenario and, even more so, in the 2DS Scenario. **These scenarios account for improvements in efficiency, but in the end the efficiency gain is outweighed by the efficiency lost in the plants being used less in future**. In other words, the plants are projected to run below their optimal power output to cope with the stringent emissions limitations, hence reducing their overall efficiency per unit of production.

Specific to the transport sector, the projected evolution up to 2050 shows that the overall emissions per kilometre from electric vehicles are expected to significantly decrease in all the scenarios considered, mainly due to a less carbon-intensive electricity supply. In particular**, at the EU28 level the projected emissions in 2050 from electric vehicles are expected to be less than half of those calculated in 2015. In 2030 electric vehicles outperform combustion vehicles by 40-50%** (in the EUCO scenario), **in 2050 by 60-70%** (in the 2DS scenario) under the WLTP test conditions. **The benefit of an electric vehicle is higher if real driving conditions are considered.** If only energy related emissions are considered, the gap between electric vehicles and internal combustion vehicles becomes further enlarged[1]. **In short, electric mobility will have a key role to play to enable the transport sector to meet the objectives set in the *Paris Agreement*.** When considering the individual countries, electric

[1] The study has been conservative in the assumption for emissions coming from manufacturing of components and battery, as they are kept constant through the whole period of analysis. Due to technological progress and a higher global uptake of renewables, manufacturing of components and battery is expected to become less carbon intensive in the future.

vehicles outperform internal combustion vehicles under all scenarios in 2030 and 2050 and in all the countries covered.

With regard to other conclusions stemming out of the transport analysis, **the study shows that if an 8- or 15-year lifetime of electric vehicles is considered**, the **energy related CO_2 emissions (WTW) further decrease by 9% and 18% respectively, thanks to an ever-increasing penetration of renewable energy sources in Europe. If instead a 2030 European EV is considered, its emissions will decrease on average by 11% (in an 8 years lifetime) and by 22% (in a 15 years lifetime) under the NPS scenario**. In practice, this indicates that the ongoing decarbonization of the electricity system provides increased GHG emission reduction of electric cars overtime. An electric car bough today in Europe will emit less and less GHG every year from now on.

Emissions from Electric Vehicles fueled with electricity provided by a biogas-powered CCGT plant have been calculated using IEA plant level emission factors at baseline. These emissions include upstream emissions from biogas but exclude transmission & distribution. The calculated emissions account for CH_4 and N_2O emissions, biogenic carbon removal however being excluded (downstream biogenic emissions are not considered either). Emissions related to the fuel/energy production impact differ slightly between the geographies considered in the scope of this analysis: Romania has the highest impact from electricity production from biogas while Italy has the lowest impact. **When comparing emissions of an Electric Vehicle fueled by the electricity produced with biomethane in a CCGT versus the direct use of biomethane in an Internal Combustion Engine vehicle, the modelled results show that electric vehicles optimize the use of biomethane in the transport sector.**

Emissions from vehicle disassembly for the different vehicle technologies have been calculated using 2015 emission factors from the GREET database, for a 160,000 km lifetime. Vehicle recycling credit and vehicle disposal emissions factors are calculated using input data from GREET (car materials), Eurostat (for the disposal route), and Zero Waste Scotland. **The benefits from recycling highlight the positive impact associated with vehicle recycling, despite the fact it is an energy-intensive process**. The overall vehicle disassembly emission factor is the lowest compared to other life cycle stages for all vehicle technologies. **Among vehicle technologies, electric vehicles have the highest emission factor from vehicle disassembly, but it is relatively low when compared to manufacturing emissions**.

2 INTRODUCTION AND CONTEXT

The European Commission has recently published the EU Long-term Vision for a Climate Neutral Economy in which the European Union (EU) aims to achieve net-zero greenhouse gas (GHG) emissions by 2050, in line with the requirements of the *Paris Agreement*, the need for global emissions to significantly curb and, more broadly, for our economies to substantially de-carbonize.

Climate change mitigation is required in all main sectors that make up the EU emissions: power generation, industry, transport, buildings, construction, and agriculture.
Out of these sectors, according to the European Commission, power generation has the highest potential for emissions reduction, mainly through the decarbonization currently underway. The reader may refer to the EU Long-term Vision for a Climate Neutral Economy for more details on reductions achieved by sector since 1990[1].
As for the transport sector, electric mobility is considered to have an important role to play. Electricity could eventually replace to a large extent fossil fuels that are still extensively used. An electric vehicle is significantly more efficient as it converts around 80 % of the energy it uses to usable power, compared with around 20 % for a conventional vehicle[2], which means it requires less energy. As the carbon intensity of electricity decreases with the increasing share of renewables in the power generation mix, the benefit from electric mobility is twofold.

In order to be able to provide an objective and reasoned assessment with regard to low-carbon power generation and zero and low emissions mobility, ERM has undertaken an independent and transparent assessment of greenhouse gas (GHG) emissions in the European Union (EU) and in 5 countries (Italy, Germany, France, Spain and Romania) along the power value chain, in the current situation and as projected in 2030 and 2050. This assessment covers the electricity value chain for the power sector and fossil fuels value chain for the transport sector, while highlighting the contribution of each phase from exploration and production, to final consumption, using reputable and reliable public sources. An innovative methodology has been developed to complete the assignment by coupling energy transition scenarios with the use of life cycle analysis (LCA).

As a result, the assessment allows a comprehensive comparison between technologies as well as allows understanding which phases of the value chain contribute the most and where the potential for improvement is the greatest. For the transport sector, this analysis allows a comparison of GHG emissions from fossil-fueled vehicles and electric vehicles. The assessment would provide the reader with a clear view of the highest potential technologies to achieve a sustainable energy transition in the EU, now and up to 2050.

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[1] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf

[2] https://www.eea.europa.eu/publications/electric-vehicles-in-europe/download

The scope of work of this assessment included the following tasks:

- identification and review of relevant literature and data sets for the assessment, covering the two transition scenarios at 2030 and 2050;
- definition of relevant assumptions to develop fit-for-purpose transition scenarios;
- baseline for the comparison of technologies in the present day (2015 data is used as the last year with complete data available for each variable):
    - review and comparison of GHG emissions per unit of electricity generated by a natural gas-fired CCGT power plant vs. a coal-fired power plant;
    - review and comparison of full life cycle GHG emissions for electric vehicles and plug-in hybrid vehicles vs. internal combustion vehicles (methane, petrol, diesel vehicles).
- for the transition scenarios developed:
    - review and comparison of GHG emissions emitted by natural gas-fired CCGT power generation vs. coal-fired power generation;
    - review and comparison of full life cycle GHG emissions for electric vehicles and plug-in hybrid vehicles vs. internal combustion vehicles (methane, petrol, or diesel vehicles).

This report presents the methodology followed to perform this assessment and the results that ERM obtained using reliable publicly available sources, ensuring the transparency and objectivity of the assessment.

3 METHODOLOGY AND ASSUMPTIONS

This chapter presents the methodology followed to develop the energy transition scenarios to 2030 and 2050, using the European Commission EUCO30 scenario for 2030, and the IEA WEO New Policies Scenario (NPS) and 2°C Scenario (2DS) for 2050.

It also presents the main data sources and methodology used for the power sector analysis, for both coal and natural gas power generation, and for the transport sector analysis, for both internal combustion vehicles and electric vehicles. In essence, an innovative approach has been developed by coupling energy transition scenarios with the use of life-cycle analysis tools.

Internationally publicly available sources have been used, ensuring the transparency and objectivity of the assessment. The main assumptions and limitations to the study have also been detailed. In particular, extrapolations of transition scenarios were carried out to extend the scope of the assessment to 2050.

3.1 DEVELOPMENT OF TRANSITION SCENARIOS FOR 2030 AND 2050

The first step of this assessment was to develop appropriate transition scenarios to 2030 and 2050. Such scenarios have been built using available data sets for the European Union (EU28), and for five geographies that consider the diversity between member states: Italy, Germany, France, Spain and Romania.

A transition scenario is not a forecast or prediction but a hypothetical construct describing a path that leads to a particular outcome, within a given timeframe.

To develop such scenarios, ERM first reviewed available scenario data sets that could be relevant, taking into account time horizons available, data included, and geographies covered. Following this review, ERM selected the following scenarios:

- The 2017 **New Policies Scenario** (NPS) developed by the International Energy Agency (IEA) in the framework of the yearly issued World Energy Outlook (WEO);
- The 2016 2°C Scenario (2DS) developed by the IEA in the framework of the yearly issued World Energy Outlook (WEO), called the **450 Scenario**; and
- The 2016 European Commission's **EUCO30** scenario.

NPS

New Policies Scenario: The New Policies Scenario of the World Energy Outlook takes into account the broad policy commitments and plans announced by countries, even if the measures to implement these commitments have yet to be identified or announced.

450 Scenario

450 Scenario (2° Degree Scenario): The 450 Scenario consists of an energy pathway in line with the goal of limiting the global increase in temperature to 2°C, by limiting the atmospheric concentration of greenhouse gases to around 450 parts per million of CO_2.

EUCO30

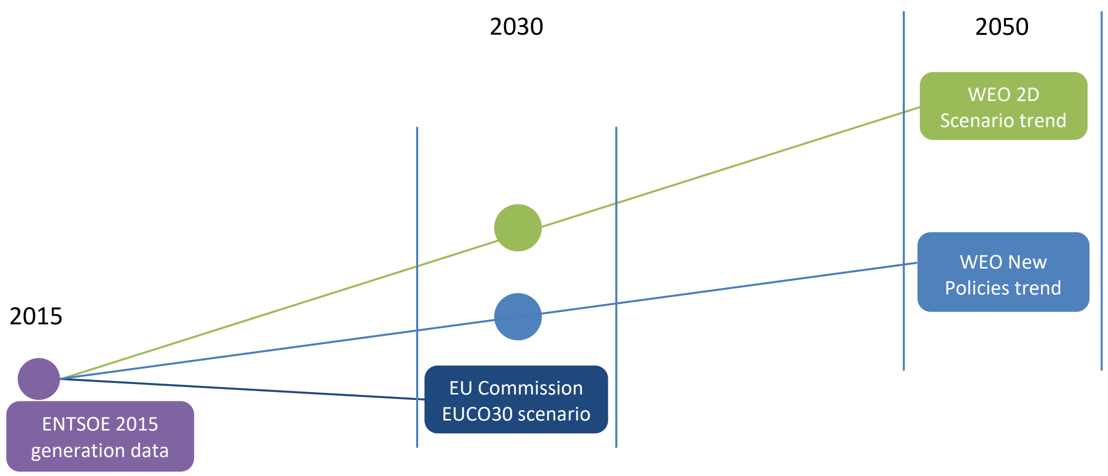
EUCO30: The European Commission EUCO30 scenario is designed to achieve the 2030 climate and energy targets of the European Council, which are: at least a 40% GHG reduction; at least 27% share of renewables in gross final energy consumption; and a 30% primary energy consumption reduction.

Table 3.1 – Data used, time period, and geographies covered in each of the selected data sets

Source	Data used	Period	Geographies
WEO NPS, WEO 2DS	- Total CO_2 emissions of power sector by fuel type (coal, oil, gas) (Mt CO_2); - Total electricity generation by type (GWh).	To 2040	EU level only
EUCO30	- Electricity generation by type (GWh); - Total CO_2 emissions from power sector (Mt CO_2).	To 2030	EU and EU countries
European Network of Transmission System Operators for Electricity (ENTSOE)	- Electricity generation (GWh) and installed capacity by fuel type (MW).	2015	EU countries

The scenarios used and periods covered are shown in Figure 3-1 below.

Figure 3-1 – Scenarios used (illustrative figure)



Estimates were made to address the following limitations of the data sets, as presented in Table 3.2 below.

Table 3.2 – Overview of limitations and estimates made

Source	Limitations	Estimates made
WEO NPS, WEO 2DS	The scenario has data at EU level only.	Extrapolations have been made based on trends from the EU level data applied to the ENTSOE country data.
	Period covered only goes up to 2040.	The trends from 2025 to 2040 have been extrapolated in order to estimate data for 2045 and 2050.
EUCO30	GHG emissions are available for the power sector without being split by fuel type.	Emissions from coal, oil, and gas have been estimated for the power sector. Please refer to Section 3.2 for further details.
	Coal is part of solid fuels.	Coal generation is from ENTSOE data and then split out into hard coal and lignite from the category 'solid fuels' used in the EUCO30 scenario.

It should be noted that the ENTSOE power generation data for 2015 has been used as a starting point (accounting for real data) for the three scenarios to align their starting point. The trend set by the EUCO30 scenario has been applied to 2015 ENTSOE electricity generation data, in order to build the EUCO30 scenario up to 2030. This shows very similar results compared to EUCO30 but with the advantage of being corrected to account for real 2015 data. Likewise, the trends set by the NPS and the 2DS scenarios have been applied to 2015 ENTSOE electricity generation data up to 2040, with the trend then extrapolated to 2050.

3.2 POWER SECTOR ANALYSIS (CCGT VS. COAL-FIRED POWER PLANT)

The power sector analysis aims to compare GHG emissions per unit of electricity generated by a natural gas-fired combined cycle gas turbine (CCGT) power plant vs. a coal-fired power plant in the current situation (2015 data point), in 2030 and 2050, following the trends set by the scenarios.

The power plant emission factor formula used for this analysis is the following[1]:

$$EF_{power\ plant} = \frac{EF_{fuel} \times FC}{EG}$$

EF_{fuel}: Emission factor of the plant's fuel type (CO_{2e}/t), including upstream and midstream emissions.
FC: Amount of fossil fuel consumed (tonnes)
EG: Net quantity of electricity generated and delivered to the grid by the plant (MWh)

[1] Based on the tool to calculate the emission factor for an electricity system for the United Nations Framework Climate Change Convention (UNFCCC) Clean Development Mechanism (CDM).

Sources considered for the power analysis are presented in Table 3.3 below:

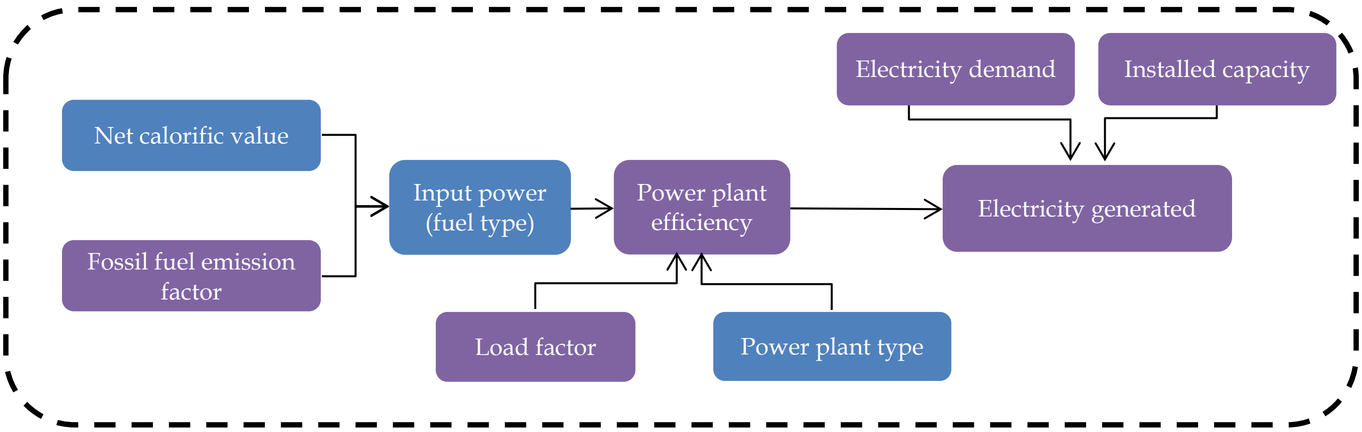
Table 3.3 - Main sources of input data and emission factors used for the power analysis

Source	Life cycle stage / input data	Fuel
IEA	Input energy	Gas
Eurostat	Input energy	Coal
ENTSOE	Current generation	Gas, coal
Eurostat for fuel inputs (& ENTSOE for generation and capacity)	Efficiency	Gas, coal
Ecoinvent 2 (weighted by supply source using IEA gas flows)	Upstream & midstream emission factor	Gas
Ecoinvent 2	Upstream & midstream emission factor	Coal
Ecoinvent 2	Downstream (plant level) emission factor	Lignite
IEA	Downstream (plant level) emission factor	Gas
IEA (& Eurostat)	Downstream (plant level) emission factor	Coal

3.2.1 *NATURAL GAS CCGT POWER PLANT ANALYSIS*

The below Figure 3-1 gives an overview of input data required to calculate GHG emissions per unit of electricity generated by a natural gas CCGT power plant.

Figure 3-2 – Input data for CCGT analysis



Variables in *purple* are the ones that have been modelled using scenario data based on projections at EU and country level. Variables in *blue* are modelled using current data at EU level.

Due to data constraints and for a better comparison between 'best-in-class' technologies, i.e. CCGT plant and hard coal plant, all gas generation is considered to be equivalent to

Combined Cycle Gas Turbine (CCGT) in efficiency. It is assumed CCGT generates electricity only (heat has not been accounted for in this analysis).

For each geography covered in the analysis (EU, Italy, Germany, France, Spain, and Romania), the following approach was used to calculate GHG emissions:

Upstream and midstream emissions:

1) IEA 2015 gas flow data was used to build a gas supply model with the share of gas imports broken down by supply source;
2) Country emission factors (CO_2e; upstream and midstream[1]) were used to establish a weighted average emission factor of the considered geography's gas supply for 2015;
3) Depending on the geography, assumptions were made on the evolution of gas supply by 2030 and 2050 (changes in gas supply sources by country of import) and this was used to vary the weighted average emission factor in the gas supply model;
4) The weighted average emission factor for the geography considered was then applied to the data for gas generation to achieve g CO_2e/kWh.

Downstream emissions:

Downstream CO_2, methane (CH_4), and nitrous oxide (N_2O) emission factors were applied to electricity generation data (2015) for natural gas at the plant level[2].

An emission factor for the total natural gas value chain, considering a CCGT power plant as the generation source, could then be obtained by adding upstream, midstream and downstream emissions, and dividing the total by 2015 electricity generation.

For 2030 and 2050, total emissions have been calculated by applying the evolution of electricity generation under the scenarios to the weighted average upstream and midstream emissions factor calculated for 2030 and 2050, and the downstream CCGT plant-level emission factor, the latter being kept constant. The evolution under the scenarios accounts for efficiency improvements over time.

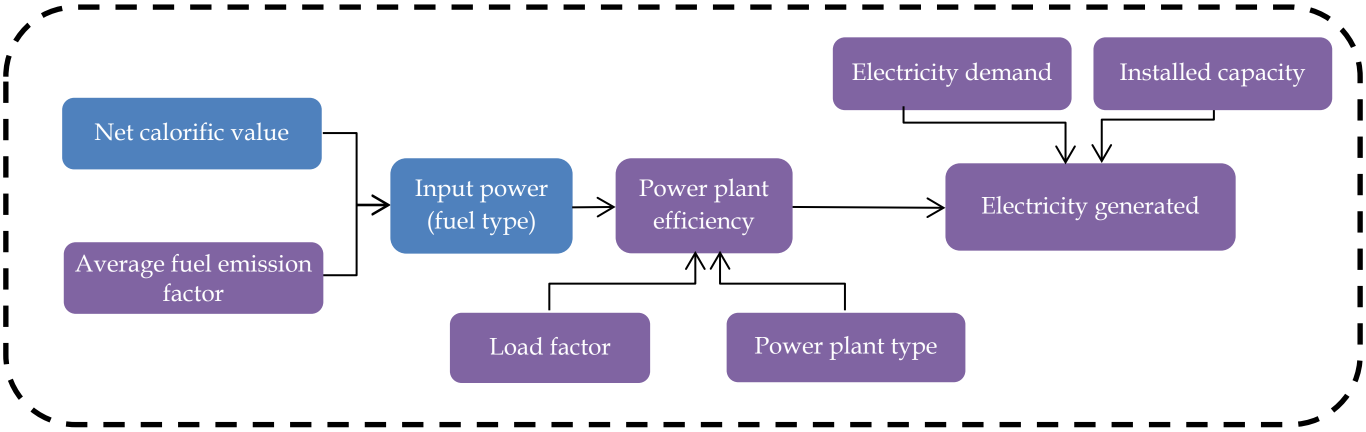
[1] Source: Ecoinvent2, 2007 emission factors

[2] Source: IEA, 2017 emission factors

3.2.2 COAL-FIRED POWER PLANT ANALYSIS

Figure 3-2 below gives an overview of input data required to calculate GHG emissions per unit of electricity generated by a coal power plant.

Figure 3-3 – Input data for coal analysis



Variables in *purple* are the ones that have been modelled using scenario data based on projections at EU and country level. Variables in *blue* are modelled using current data at EU level.

For all markets, this analysis is performed both for hard coal generation and for lignite generation. As is the case for CCGT power plants, it is assumed coal plants generate electricity only, not heat.

For each geography covered in the analysis, the following approach was used to calculate GHG emissions:

Upstream and midstream emissions:

Coal plant efficiency was calculated to estimate the volume of coal burned in the power plant. Country emission factors (upstream and midstream[1]) were applied to total fuel inputs to calculate the upstream and midstream emissions.

Downstream emissions:

1) The emission factor at plant level was calculated by applying the formula introduced in Section 3.2, using the emission factor for bituminous coal or for lignite.
2) A multiplier was applied (the ratio of CO_2:CH_4 & N_2O IEA emission factors) to take into account methane (CH_4) and nitrous oxide (N_2O) emissions, in addition to CO_2 emissions obtained in step 1. This multiplier also accounts for the different Global Warming Potentials of these three GHGs, and is taken from the latest IEA dataset.

[1] Source: Ecoinvent2, 2007 emission factors

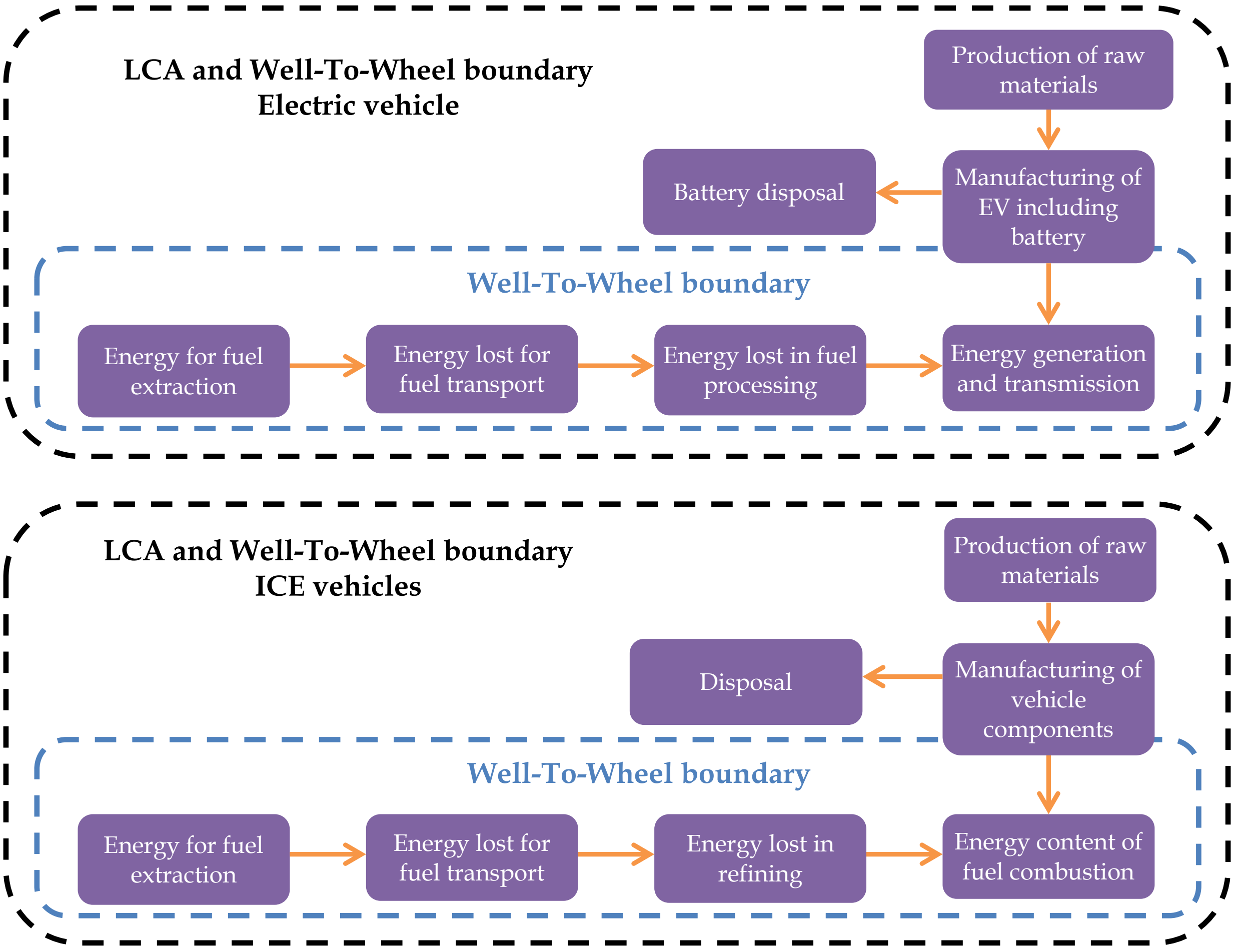
An overall emission factor for coal power generation could then be obtained by adding upstream, midstream and downstream emissions, and dividing the total by the amount of electricity generated.

3.3 *TRANSPORT SECTOR ANALYSIS (INTERNAL COMBUSTION VEHICLES VS. ELECTRIC VEHICLES)*

The transport sector analysis compares GHG emissions per kilometre travelled by an electric vehicle vs. an internal combustion vehicle in the current situation (2015 data), in 2030 and 2050. It follows the trend for power sector emissions set by the scenarios and natural gas upstream- and midstream-supply emissions set by the gas supply model.

A hybrid LCA and well-to-wheel methodology was applied for this analysis. Figure 3-4 below gives an overview of the methodology:

Figure 3-4 – Overview of processes differing significantly between vehicle types (electric vehicle & internal combustion engine vehicle)



The methodology chosen for this analysis is the one suggested by the Swiss Federal Laboratories for Materials Science and Technology (EMPA)[1], which, for a battery vehicle,

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[1] https://www.empa.ch/documents/56122/458579/LCA-Mobilitaetsvergleich_Bericht.pdf/824aec56-3393-439e-8bc9-d1a365041e4d

accounts for the GHG impact of both the battery and vehicle components (glider and drivetrain).

The lifetime of a vehicle considered in this methodology is 160,000 km, except for diesel vehicle (208,000 km). The analysis is based on publicly available datasets, for which a range of results (low, medium, and high, depending on the level of impact of components & battery combined) have been included. Where possible, conservative approaches have been followed and data from the same sources have been considered to ensure consistency.

For all vehicles, the following life cycle stages have been considered in the analysis:

- Upstream fuel/electricity production, transport-distribution losses in the network, and fuel dispensing;
- Components manufacturing;
- Fuel combustion;
- Battery manufacturing (for electric vehicles);
- Disassembly and disposal (including battery disposal for electric vehicles).

The analysis was performed for the following vehicle technologies:

- High-pressure natural gas (CNG) vehicle;
- Liquefied natural gas (LNG) vehicle;
- Electric vehicle;
- Hybrid electric vehicle;
- Diesel vehicle;
- Petrol vehicle;
- Biogas vehicle (biomethane); and
- Electric vehicle fuelled by a biogas CCGT power plant.

The assessment covered fuel cell, spark-ignition hybrid electric vehicle (SI HEV), and spark-ignition internal combustion engine vehicle (SI ICEV) types. The type of electric vehicle considered in the analysis is an average electric vehicle as defined by EMPA, the Swiss Federal Laboratories for Materials Science and Technology.

The analysis was performed on car segments A, B, and C, which account for the three smallest car segments on the European market, the C segment being medium cars. The segment C is the one chosen as basis for the comparison.

The following vehicle data were collected for car segments A, B, and C from the UK Vehicle Certification Agency database based on official testing: Emission factor; Fuel consumption / 100 km; carbon monoxide (CO) emissions; total hydrocarbon (THC) emissions; nitrogen oxide (NOx) emissions; Particulates; and Electricity consumption / km, under New

European Driving Cycle (NEDC) test conditions. Vehicle weight came from the European Environment Agency database.

For all vehicle data, a weighted average based on sales values for the 5 most sold car models per segment (A, B, and C[1]) in Europe in 2017 was calculated for each vehicle fuel type (petrol, diesel, electricity/petrol, electricity, and natural gas), throughout the analysis.

As the manufacturer's data were only available under NEDC test conditions, in order to get emissions under worldwide harmonized vehicle test procedure (WLTP) conditions, a conversion factor from the European Commission Joint Research Centre was applied. Likewise, to compare those with real driving emissions (RDE), a conversion factor from the International Council on Clean Transportation (ICCT) and the Netherlands Organization for applied scientific research (TNO) was used to convert NEDC emissions into RDE.

Criteria pollutants emitted by the different vehicle technologies have also been considered. Nitrogen oxide (NOx), particulate matter, total hydrocarbon emissions (THC), and carbon monoxide (CO) emissions have been collected from the UK Vehicle Certification Agency database, under New European Driving Cycle (NEDC) test conditions. They have then been converted into emissions under worldwide harmonized vehicle test procedure (WLTP) conditions and under real driving emissions (RDE) conditions, using appropriate conversion factors identified in literature (i.e. from *Marotta et al* for the WLTP conversion, and from *Pielecha et al* for the RDE conversion of CO, THC, and particulates, and from the ICCT for the RDE conversion of NOx emissions).

Network and charging losses have been considered at 8% each[2].

Sources considered for each of these impacts are presented in Table 3.4 below:

Table 3.4 – Main sources of data used for the transport analysis

Emission factor source	Life cycle stage / input data	Vehicle type
EMPA	Vehicle components, including battery	CNG, LNG, biogas, electric
Ecoinvent 2	Upstream fuel production	LNG, biogas
Weighted average emission factors for 2015, 2030 and 2050 (as calculated for the natural gas analysis)	Upstream natural gas production	CNG
IEA (plant level, 2015)	Upstream energy production	Electric
GREET (2015)	Vehicle efficiency	CNG, LNG, biogas, electric

[1] For segment C: most sold EVs considered are WV e-Golf, Nissan Leaf and Hyundai Ionic; most sold petrol and diesel cars considered are WV Golf, Skoda Octavia, Opel Astra, Ford Focus and Renault Megane; CNG cars considered are WV Golf, Skoda Octavia, Fiat Qubo.

[2] Reference: considering publications (i) Chlebis, P., Tvrdon, M.; and (ii) Krieger, E.M., Arnold, C.B., 92% charging efficiency can be considered as an intermediate value within the efficiency ranges obtained.

GREET (2015)	Combustion	CNG, LNG, biogas
Manufacturer data (Volkswagen and Mercedes)	Vehicle production	Diesel, petrol
UK vehicle certification agency	Vehicle data at use stage	Diesel, petrol, electric, natural gas
Joint Research Centre – European Commission	Diesel, gasoline consumption mix at refinery	Diesel, petrol
European Environment Agency	Vehicle weight	Diesel, petrol, electric, natural gas

Main assumptions considered for the transport analysis include the following:

- An electric vehicle efficiency increase of 24% to 2030, and 34% to 2050 (with respect to baseline);
- An internal combustion engine vehicle efficiency increase of 20% to 2030, and 25% to 2050 (with respect to baseline);
- A biofuels content of 10% ethanol in petrol and 7% biodiesel in diesel;
- A biomethane content of 10% in compressed natural gas in 2030 and 2050;
- A vehicle lifetime of 160,000 km, except for diesel vehicles, which have been normalized to 208,000 km.

In addition, manufacturing emissions have been considered constant through time for comparison reasons. CO_2 conversion ratios between test values (NEDC – WLTP) and real world emissions were taken from the Joint Research Center of the European Commission. Pollutant emissions consider fuel combustion only in real driving conditions, calculated from manufacturer's data applying conversion factors from literature.

For all vehicle technologies, emission factors pertaining to each life cycle stage considered in the analysis have been added up as appropriate to get the overall GHG emissions per kilometre within the boundary considered in the transport analysis, for each geography considered.

For 2030 and 2050, total emissions have been calculated by applying the pattern of evolution of electricity generation under the WEO NPS and WEO 2DS scenarios to the emissions calculated for 2015. For the EUCO30 scenario, the original trend set by the scenario has also been applied, up to 2030, to the emissions calculated for 2015.

4 *RESULTS*

The results of the assessment are presented in this section, starting from the current situation (2015 data) and then detailing the projected results at 2030 and 2050 following the trends set by the EUCO30, WEO NPS, and WEO 2DS scenarios.

For more clarity, the results are separately presented for the baseline for both power and transport (Section 4.1), then for the power sector by 2030 and 2050 (Section 4.2), and for the transport sector by 2030 and 2050 (Section 4.3).

The results of the power sector analysis are broken down by geography and by stage of the value chain, whereas the results of the transport sector analysis are broken down by type of vehicle and by life-cycle stage, considering a well-to-wheel + LCA approach as previously described in the methodology.

4.1 *BASELINE FOR POWER AND TRANSPORT*

In the baseline year (2015):

- In the baseline year (2015 data), the power analysis shows that specific GHG emissions from coal-fired power plant exceed specific GHG emissions from natural gas power plants. Moreover, overall GHG emissions from coal-fired power plant are higher than the ones from natural gas power plants at the EU level and in the countries analysed, with the exception of France, due to the higher use of natural gas vs. coal-fired power plants. In terms of carbon intensity, CCGT significantly outperforms coal-fired plants, and are approximately 60% lower in carbon intensity when considering the full value chain. For both CCGT and coal-fired plants, upstream and midstream emissions are significantly lower than downstream emissions associated to the operation of the power plants over their lifetime.
- The transport analysis for C segment vehicles shows, both under worldwide-harmonized vehicle test procedure (WLTP) conditions and when considering real driving emissions, that electric vehicles already outperform compressed and liquefied natural gas vehicles, as well as petrol and diesel vehicles in all the geographies considered. Electricity has lower final GHG emissions compared to fossil fuels. Electric vehicles have a higher tank-to-wheel efficiency in balanced electricity systems compared to compressed and liquefied natural gas vehicles, and petrol and diesel vehicles. Analogue results are found when comparing also A and B segments of vehicles. This is also the case when considering real driving emissions (RDE).

The baseline scenario represents the situation at the present day, based on the most recent publicly available (and verifiable) data sets. In particular, electricity generation considered throughout the baseline analysis is ENTSOE power generation data for 2015.

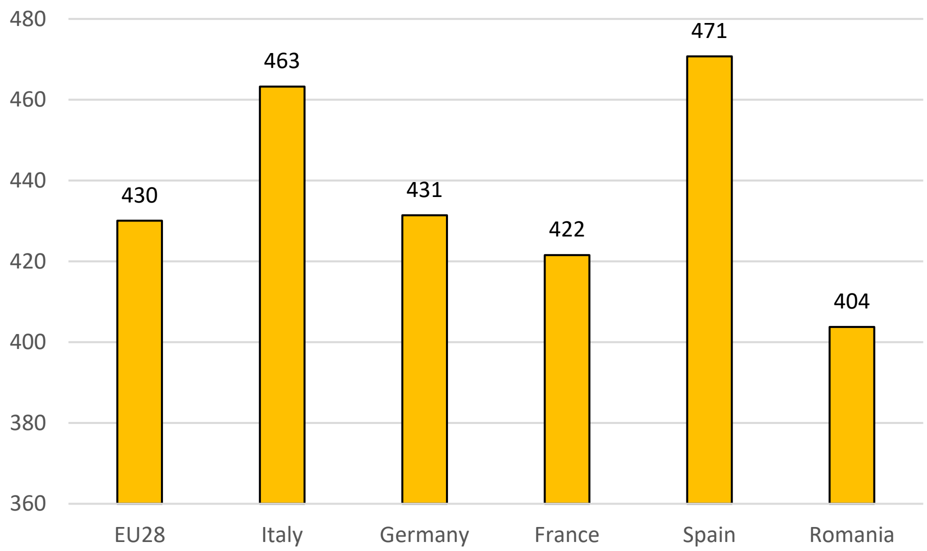
4.1.1 CCGT PLANT AND NATURAL GAS VALUE CHAIN

Baseline CCGT plant and natural gas value chain results are presented below for each of the geographies considered in the analysis, in terms of (i) emission factor, and (ii) break down by stage of the value chain (upstream & midstream, and downstream).

Table 4.1 – CCGT plant emission factor and natural gas value chain stage emissions (g CO_2e/kWh) by geography

Geography	CCGT emissions (gCO_2e/kWh)
EU28	430.06
Italy	463.24
Germany	431.40
France	421.55
Spain	470.73
Romania	403.77

Figure 4-1 – CCGT plant emission factor and natural gas value chain stage emissions (g CO_2e/kWh) by geography

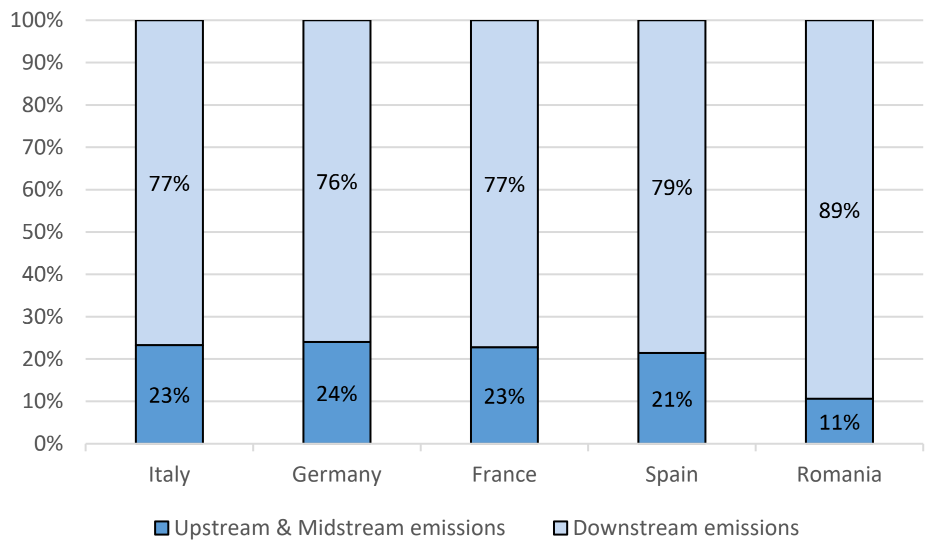


This graph shows that the highest emission factors are those of Spain and Italy. This may be explained by the fact these countries current gas supply comes from LNG import and countries of supply that have highest natural gas production emission factors. Downstream emissions account for the greatest share of total natural gas emissions across all geographies considered in this study.

Table 4.2 – CCGT emissions by country and value chain stage (%)

Country	Upstream & Midstream emissions	Downstream emissions
Italy	23%	77%
Germany	24%	76%
France	23%	77%
Spain	21%	79%
Romania	11%	89%

Figure 4-2 – CCGT emissions by country and value chain stage (%)



Upstream and midstream emissions factor for Russia is relatively high when compared to, for example, natural gas produced onshore in the Netherlands. Likewise, Romania has the lowest upstream & midstream contribution to overall emissions as gas supply is mainly domestic and therefore does not travel as far. To reflect this, an emission factor for natural gas production in onshore Russia has been chosen as an analogue, where gas supply is also mainly domestic and for which data are available.

4.1.2 HARD COAL

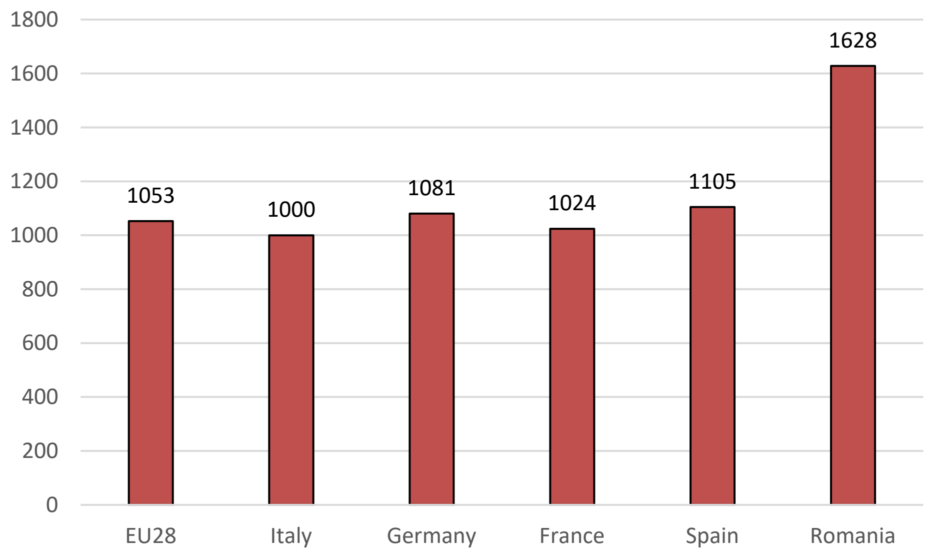
Baseline hard coal-fired power plant results are presented below for each of the geographies considered in the analysis, in terms of (i) emission factor, and (ii) value chain stage (upstream & midstream, and downstream).

Table 4.3 – Hard coal plant emission factors and emissions by value chain stage by geography (g CO_2e/kWh)

Country	Hard coal plant emissions (gCO_2e/kWh)
EU28	1052.80
Italy	999.68
Germany	1080.69
France	1023.99
Spain	1104.95
Romania*	1627.90

*Note: Unlike for other countries, lignite has been considered for Romania, and not hard coal.

Figure 4-3 – Hard coal emission factor (g CO_2e/kWh) by geography

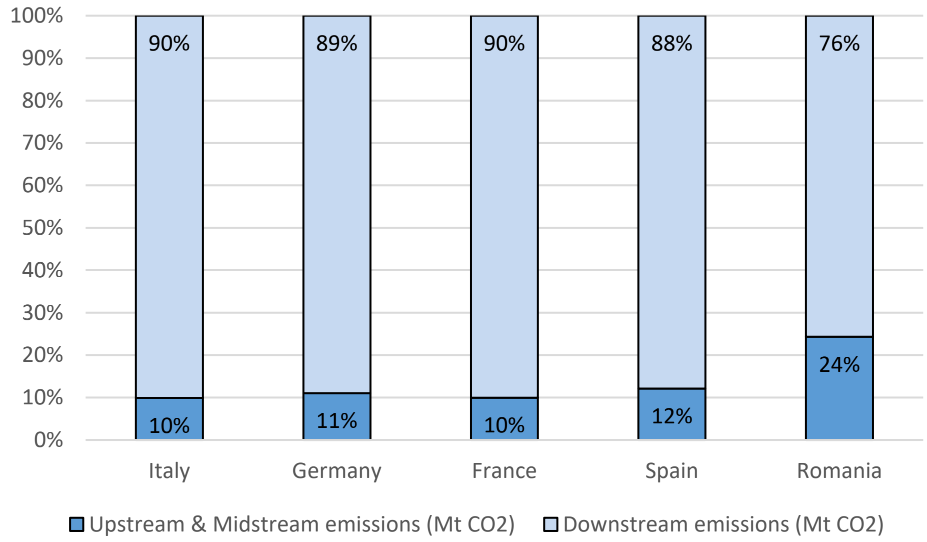


Romania has the highest emission factor out of the geographies considered as the main fuel used is lignite with a very low calorific value, as opposed to hard coal, which is predominantly used in the other countries.

Table 4.4 – Hard coal emissions by country and value chain stage (%)

Country	Upstream & Midstream emissions	Downstream emissions
Italy	10%	90%
Germany	11%	89%
France	10%	90%
Spain	12%	88%
Romania	24%	76%

Figure 4-4 – Hard coal emissions by country and value chain stage (%)



As is the case for natural gas emissions, downstream emissions account for the greatest share of coal emissions. For Romania, the share of upstream and midstream emissions is higher because, due to the low calorific value of lignite burned in Romania, a higher volume must be transported per kWh of electricity generated.

4.1.3 CCGT VS. COAL

Baseline CCGT vs. coal-fired power plant results are presented below for each geography, in terms of (i) emissions factors, (ii) overall emissions, and (iii) value chain stage (upstream & midstream, and downstream).

Table 4.5 - CCGT vs. coal emission factors (g CO_2e/kWh) by geography

Geography	CCGT emissions (gCO_2e/kWh)	Coal plant emissions (gCO_2e/kWh)
EU28	430.06	1207
Italy	463.24	999.68
Germany	431.40	1242.52
France	421.55	1023.99
Spain	470.73	1104.95
Romania	403.77	1627.90

In the baseline situation, coal emission factors are about 2 to 2.5 times higher than gas emission factors in all geographies, except Romania, where coal emission factors is 4 times higher than gas emission factors. It should be noted that, as stated previously, for Romania, coal emissions mainly come from lignite, which has higher emissions.

Table 4.6 below provides an overview of generation, capacity and load factors by geography for both hard coal and natural gas, in the baseline year.

Table 4.6 - Natural gas and hard coal generation, capacity and load factor, 2015

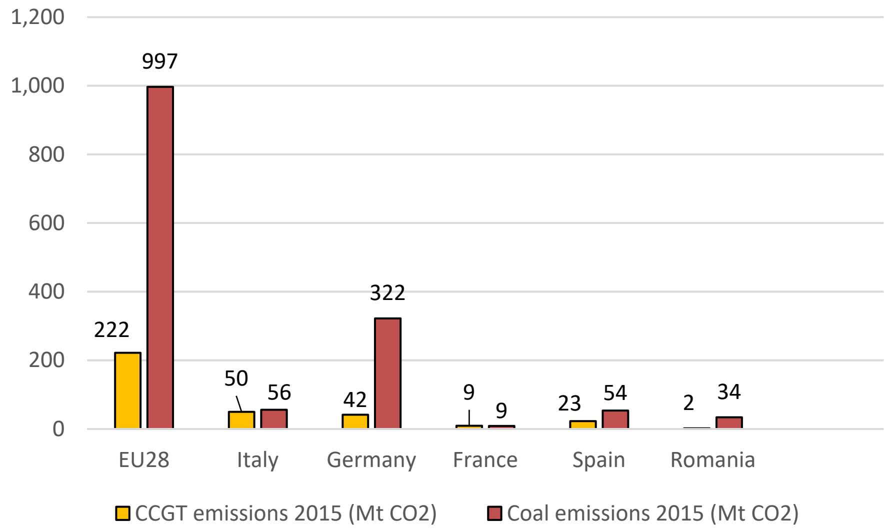
Geography	Natural gas generation (GWh)	Natural gas capacity (MW)	Hard coal generation (GWh)	Hard coal capacity (MW)	Natural gas load factor	Hard coal load factor
EU28	395 375	210 235	407 369	104 574	0.21	0.44
Italy	91 451	39 292	38 380	6 357	0.26	0.69
Germany	53 155	28 325	107 131	26 480	0.21	0.46
France	22 082	10 831	8 605	3 007	0.23	0.33
Spain	48 594	32 329	48 581	9 881	0.17	0.56
Romania*	4 496	2 025	14 467	3 778	0.25	0.44

*Note: Unlike for other countries, lignite has been considered for Romania, and not hard coal.

Table 4.7 – CCGT vs. coal emissions (Mt CO_2e) by geography and value chain stage

	CCGT			Coal		
Geography	Upstream & Midstream emissions (Mt CO_2)	Downstream emissions (Mt CO_2)	Total emissions (Mt CO_2)	Upstream & Midstream emissions (Mt CO_2)	Downstream emissions (Mt CO_2)	Total emissions (Mt CO_2)
EU28	32.88	137.16	170.03	116.65	880.08	996.73
Italy	9.85	32.51	42.36	5.53	50.36	55.90
Germany	5.42	17.51	22.93	32.83	289.29	322.12
France	2.12	7.19	9.31	0.88	7.93	8.81
Spain	4.89	17.98	22.87	6.49	47.19	53.68
Romania	0.08	1.81	1.89	8.27	25.72	34.00

Figure 4-5 – CCGT vs. coal emissions (Mt CO_2e) by geography and value chain stage



In the baseline year (2015), the power analysis shows that emission factors of coal-fired power plants greatly exceed emission factors from natural gas CCGT power plants. In terms of overall emissions, coal emissions are higher than natural gas with the notable exception of France, where total GHG emissions from natural gas are higher than those from coal, due to the much higher use of natural gas.

When considering the overall value chain, both for natural gas CCGT and coal-fired power plants, downstream GHG emissions far exceed upstream and midstream GHG emissions. This is valid in all countries considered in the assessment. Nevertheless, natural gas GHG emissions are highly conditioned by the leaked CH_4 emissions in the upstream and midstream phases of natural gas supply, as CH_4 global warming potential is several times higher than CO_2 global warming potential. If CH_4 leakages in the gas supply chain were higher than those estimated by publicly available studies, natural gas emissions would be significantly increased.

4.1.4 TRANSPORT

The following results are obtained in the baseline situation by vehicle technology, broken down by life cycle stage, for segment C vehicles, which are medium-sized cars, considering an average consumption electric vehicle as defined by the EMPA methodology followed, to allow for comparison across vehicle technologies. Upstream, midstream and downstream emissions are included. Biofuels content are 10% ethanol in petrol, 7% biodiesel in diesel.

Figure 4-6 –Vehicle GHG emission factors (g CO_2e/km) by vehicle technology, and by life cycle stage, at EU level, for segment C vehicles, under WLTP conditions

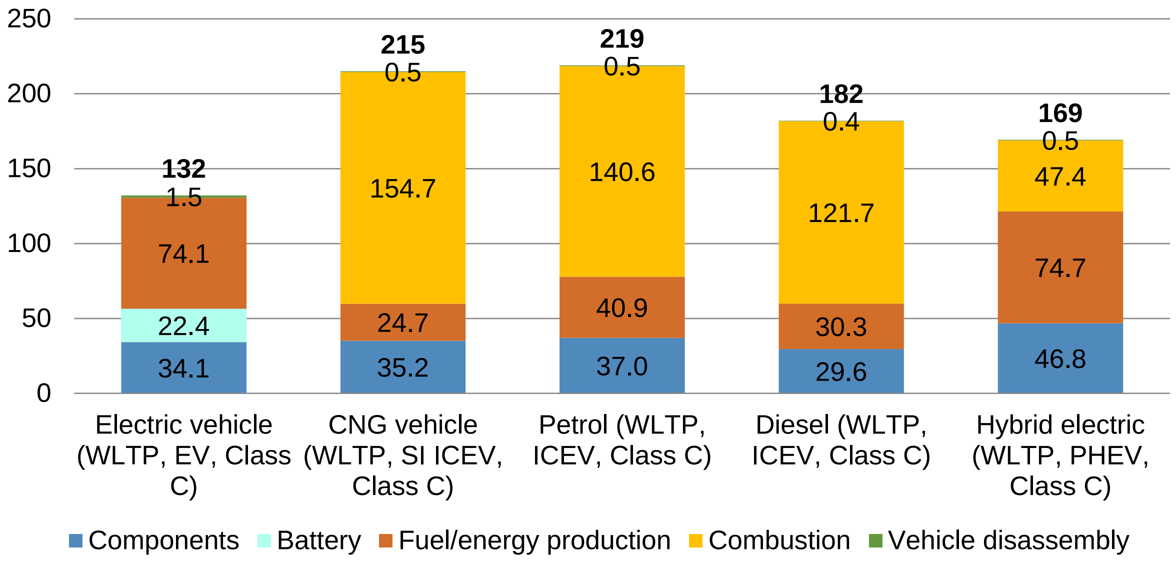
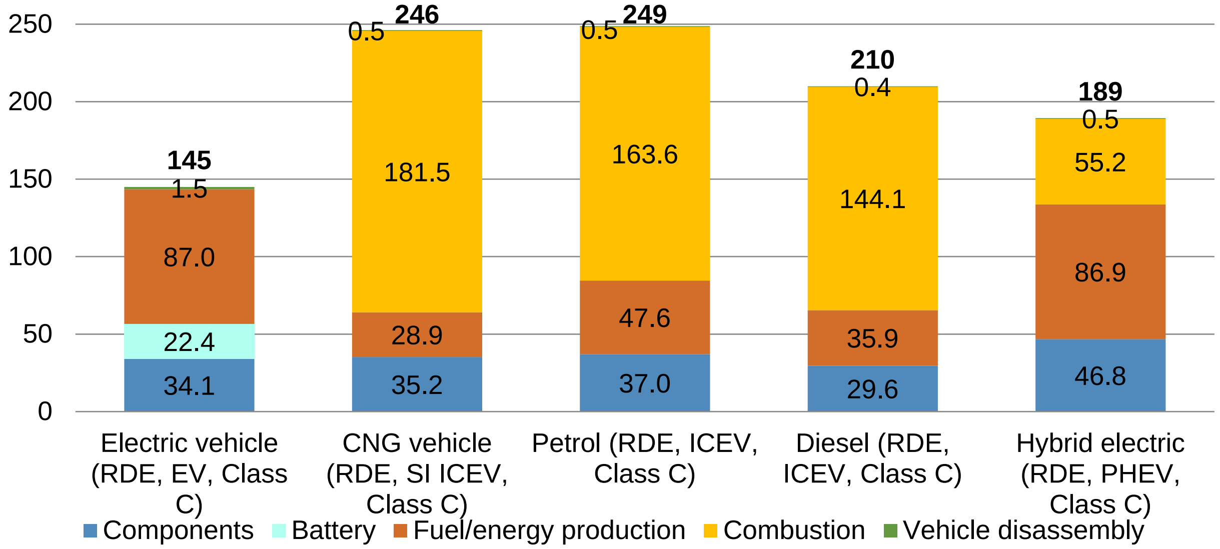


Figure 4-7 –Vehicle GHG emission factors (g CO_2e/km) by vehicle technology, and by life cycle stage, at EU level, for segment C vehicles, under Real-Driving Emission conditions



- Overall GHG emissions

In the baseline year (2015), the transport analysis for C segment vehicles shows, under worldwide-harmonized vehicle test procedure (WLTP) conditions and when considering real driving emissions, at EU level, that electric vehicles outperform compressed and liquefied natural gas vehicles as well as petrol and diesel vehicles, due to lower final GHG emissions of electricity versus natural gas fuel[1]. Electric vehicles have a higher tank-to-wheel efficiency in balanced electricity systems compared to internal combustion vehicles.

Table 4.8 – Reduction of Electric Vehicles GHG emissions versus Internal Combustion Engine vehicles, baseline for Europe

		CNG	PETROL	DIESEL	PHEV
WLTP Conditions	Well-to-Wheel: Electric vehicle vs.	-59%	-59%	-51%	-39%
	Well-to-Wheel + LCA: Electric vehicle vs.	-39%	-40%	-27%	-22%
RDE Conditions	Well-to-Wheel: Electric vehicle vs.	-59%	-59%	-51%	-39%
	Well-to-Wheel + LCA: Electric vehicle vs.	-41%	-42%	-31%	-23%

1 This is true also under New European Driving Cycle (NEDC) condition.

Embedded GHG emissions from vehicle components are higher for an electric vehicle due to the high impact of Li-ion battery production. No significant difference was found between embedded GHG emissions of electric and internal combustion vehicle components excluding the battery.

- Vehicle disassembly

Emissions from vehicle disassembly for the different vehicle technologies have been calculated using 2015 emission factors from the GREET database, for a corrected 160,000 km[1] traveled distance over the vehicle lifetime, allowing for comparison across the vehicle technologies.
Vehicle recycling credit and vehicle disposal emissions factors were calculated using input data from GREET (car materials), Eurostat (for the disposal route), and Zero Waste Scotland.

The benefits from recycling highlight the positive impact associated with vehicle recycling, despite the fact it is an energy-intensive process. The overall vehicle disassembly emission factor is the lowest compared to other life cycle stages for all vehicle technologies. Among vehicle technologies, electric vehicles have the highest emission factor from vehicle disassembly.

- Criteria pollutants

Further to the GHG emissions analysis, criteria tailpipe pollutants emitted by vehicles, which have an impact on public health and the environment at local level, have also been considered.

Nitrogen oxide (NOx), particulate matter, total hydrocarbon emissions (THC), and carbon monoxide (CO) emissions have been collected from the UK Vehicle Certification Agency database, under New European Driving Cycle (NEDC) test conditions. They have then been converted into emissions under worldwide harmonized vehicle test procedure (WLTP) conditions and under real driving emissions (RDE) conditions, using appropriate conversion factors identified in literature (i.e. from *Marotta et al* for the WLTP conversion, and from *Pielecha et al* for the RDE conversion of CO, THC, and particulates, and from the ICCT for the RDE conversion of NOx emissions).

Electric vehicles produce zero local emissions. Hybrid electric and compressed natural gas (CNG) vehicles have the lowest impacts when it comes to tailpipe pollutant emissions, while petrol vehicles have the highest impact for CO emissions and THC emissions, and diesel vehicles have the highest impact for NOx emissions and particulate matter emissions, based on data derived from official testing. It can be noted that hybrid electric vehicles outperform natural gas vehicles when it comes to nitrogen oxide emissions, whereas natural gas vehicles have lower carbon monoxide emissions. The representativeness of the results reached is considered to be limited due to the methodology followed, as it does not consider very relevant factors for pollutant emissions production such as aging or clogging of abetment systems. Other relevant studies in the field (egg. *Josh Miller* and *Vicente Franco*, ICCT, 2017) show a much bigger disparity between EVs and ICE results.

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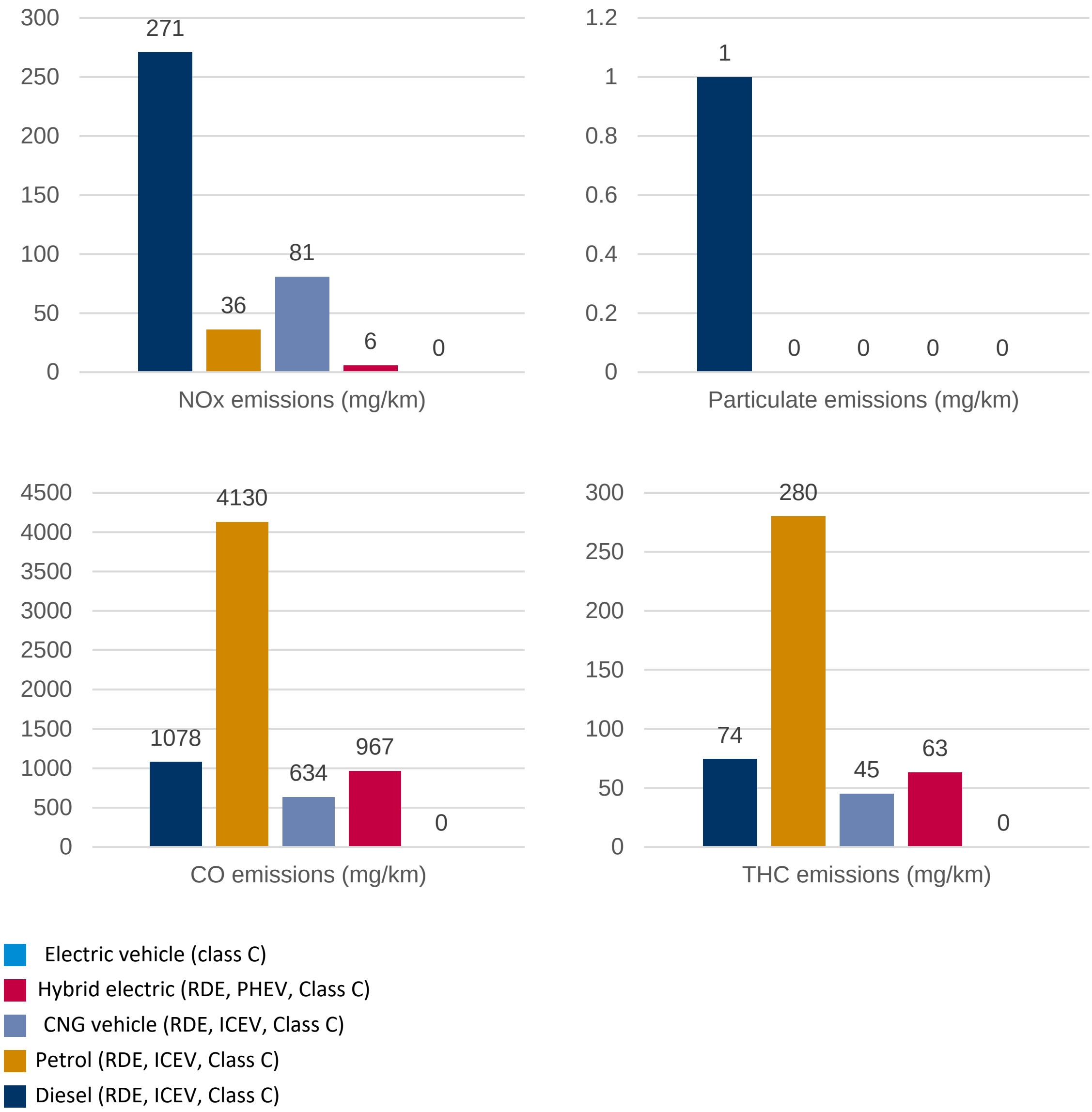
[1] Except for diesel vehicles (208,000 km)

Figure 4-8 – pollutant emissions of the diverse technologies in Real Driving Conditions, based exclusively on test data as provided by manufacturers (Class C vehicles)



- Use of biomethane in transport

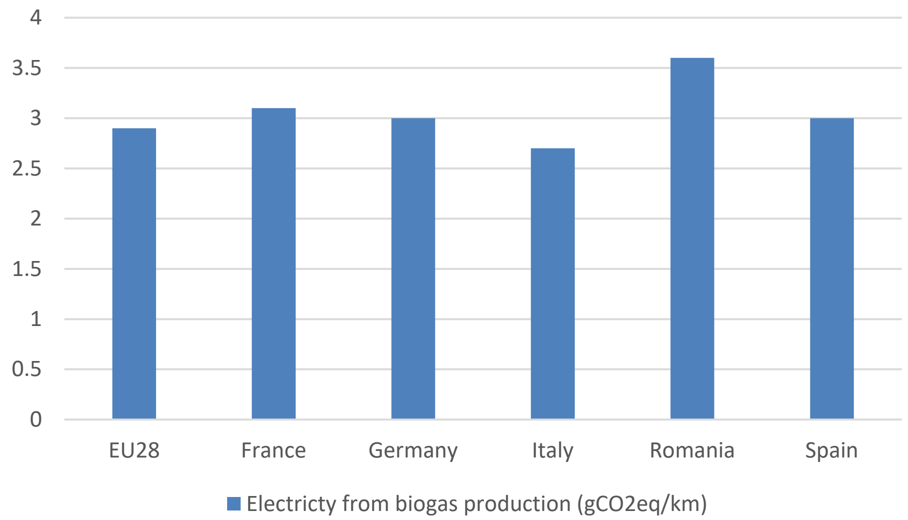
Vehicle and fuel production emissions are similar for biomethane vehicles as for natural gas vehicle types while CO_2 combustion emissions of biomethane are lower (carbon-neutral) since they offset the CO_2 uptake from the air by the bio-based feedstock.

Emissions for electric vehicles (light weight considered) fueled with electricity provided by a biomethane-powered CCGT plant have been calculated using IEA plant level emission factors at baseline. These emissions include upstream emissions from biomethane but exclude transmission & distribution. The calculated emissions account for CH_4 and N_2O

emissions, biogenic carbon removal however being excluded (downstream biogenic emissions are not considered either).

Emissions related to the fuel/energy production impact differ slightly between the geographies considered in the scope of this analysis as follows:

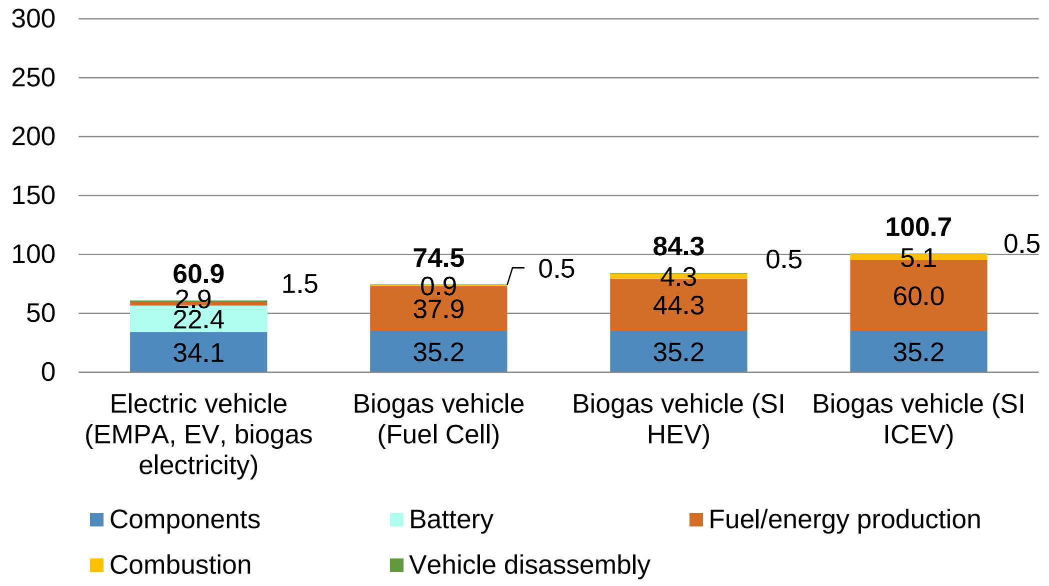
Figure 4-9 – Emissions of electric vehicles related to the fuel/energy production when electricity is produced by a CCGT fueled with biomethane



We can see Romania has the highest impact from electricity production from biomethane while Italy has the lowest impact.

When comparing emissions of an Electric Vehicle fueled by the electricity produced with biomethane in a CCGT versus the direct use of biomethane in an Internal Combustion Engine vehicle, the modelled results show that electric vehicles optimize the use of biomethane in the transport sector.

Figure 4-10 –Vehicle GHG emission factors (g CO_2e/km) for biomethane use in transport, at EU level, for segment C vehicles, under Real-Driving Emissions



4.2 POWER SECTOR ANALYSIS (NATURAL GAS CCGT VS. COAL-FIRED POWER)

- At the 2030 time horizon, the power analysis shows contrasted results in terms of the relative importance of GHG emissions from coal-fired power plants vs. natural gas fired power plants, depending on the scenario taken into account. At the EU28 level, when considering the EUCO30 scenario, GHG emissions associated with coal-fired power plants still exceed those from natural gas power plants, whereas emissions from coal significantly decrease when considering the NPS Scenario and, even more so, when considering the 2DS Scenario. With regard to the carbon emission factors, coal emission factors are the highest in the 2DS scenario, across all geographies considered in the study. Natural gas CCGT emission factors are comparable between the scenarios and geographies, for all geographies.
- At the 2050 time horizon, the power analysis shows a decrease in GHG emissions in all the scenarios considered (NPS and 2DS). At the EU28 level, no coal-fired plants are projected to be in operation in 2050 in all scenarios, thus resulting in zero emissions from coal, whereas emissions from natural gas plants are largely dependent on the scenario considered. This result reflects the different trajectories in terms of power production when considering the broad policy commitments and plans announced by countries as set in the NPS scenario, and the more substantial transition required to meet the trends set by the 2DS Scenario. With regard to the natural gas CCGT emission factors, they are projected to increase in 2050 vs. 2030 in both the NPS Scenario and, even more so, in the 2DS Scenario. These scenarios account for improvements in efficiency but in the end, the efficiency gain is outweighed by the efficiency lost in the plants being used less in future. In other words, the plants are projected to run below capacity to keep the stringent emissions limitations, hence reducing their overall efficiency per unit of production.

4.2.1 RESULTS FOR 2030 AND 2050

This section contains 2030 and 2050 results based upon, respectively, (i) the EUCO30 Scenario, (ii) the NPS Scenario, and the (iii) 2DS Scenario. Emissions include upstream, midstream and downstream parts of the value chain.

2030 and 2050 CCGT vs. coal-fired power plant total power emissions results are presented below, followed by emission factors for each of the geographies and scenarios:

Figure 4-11 - EUCO30 Scenario in 2030: CCGT vs. coal emission factors (gCO$_2$e/kWh) by geography

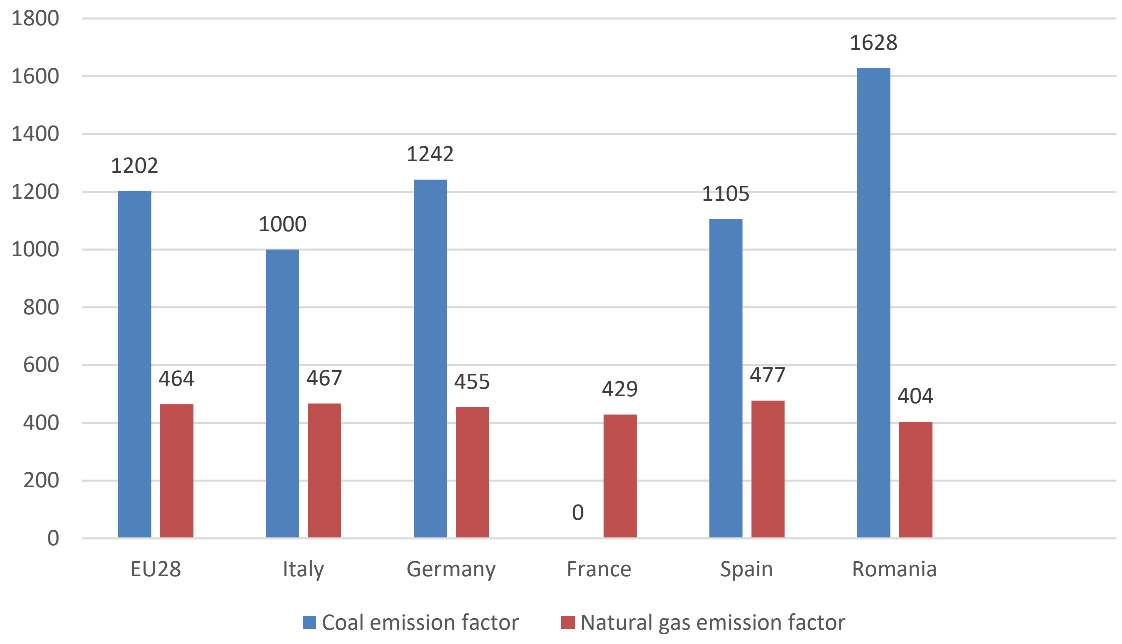


Figure 4-12 – CCGT vs. coal emission factors (g CO$_2$e/kWh) in 2050 by geography and scenario

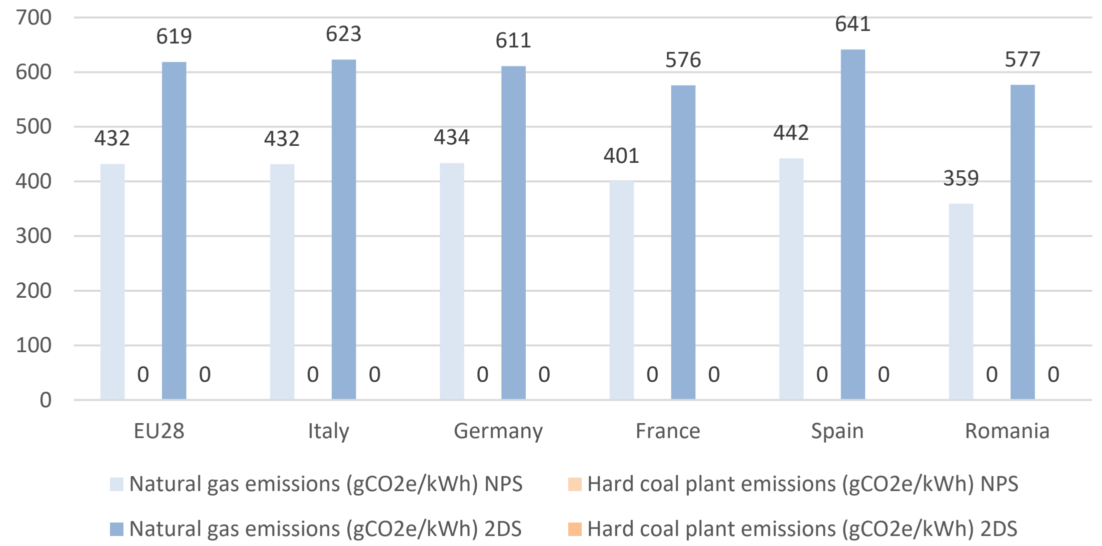


Figure 4-13 – CCGT vs. coal emissions (Mt CO_2e) in 2030 by geography and scenario

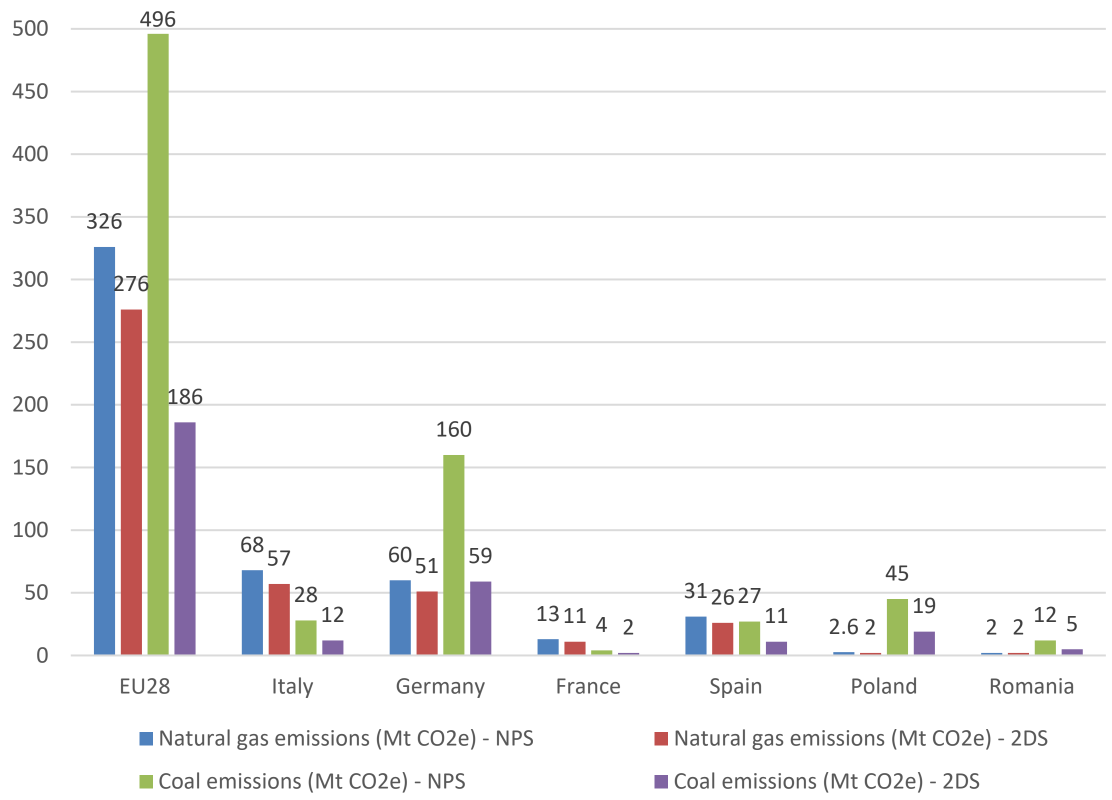


Figure 4-14 – CCGT vs. coal emissions (Mt CO_2e) in 2050 by geography and scenario

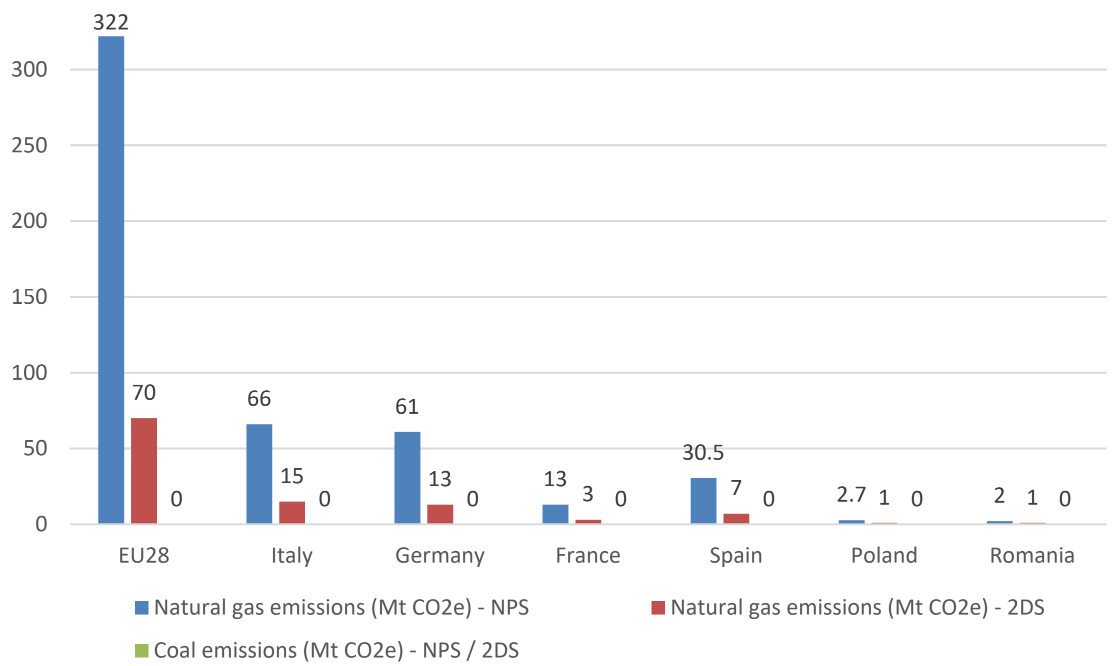


Figure 4-15 – NPS & 2DS Scenario in 2030 and 2050: CCGT emission factors (gCO_2e/kWh) by geography

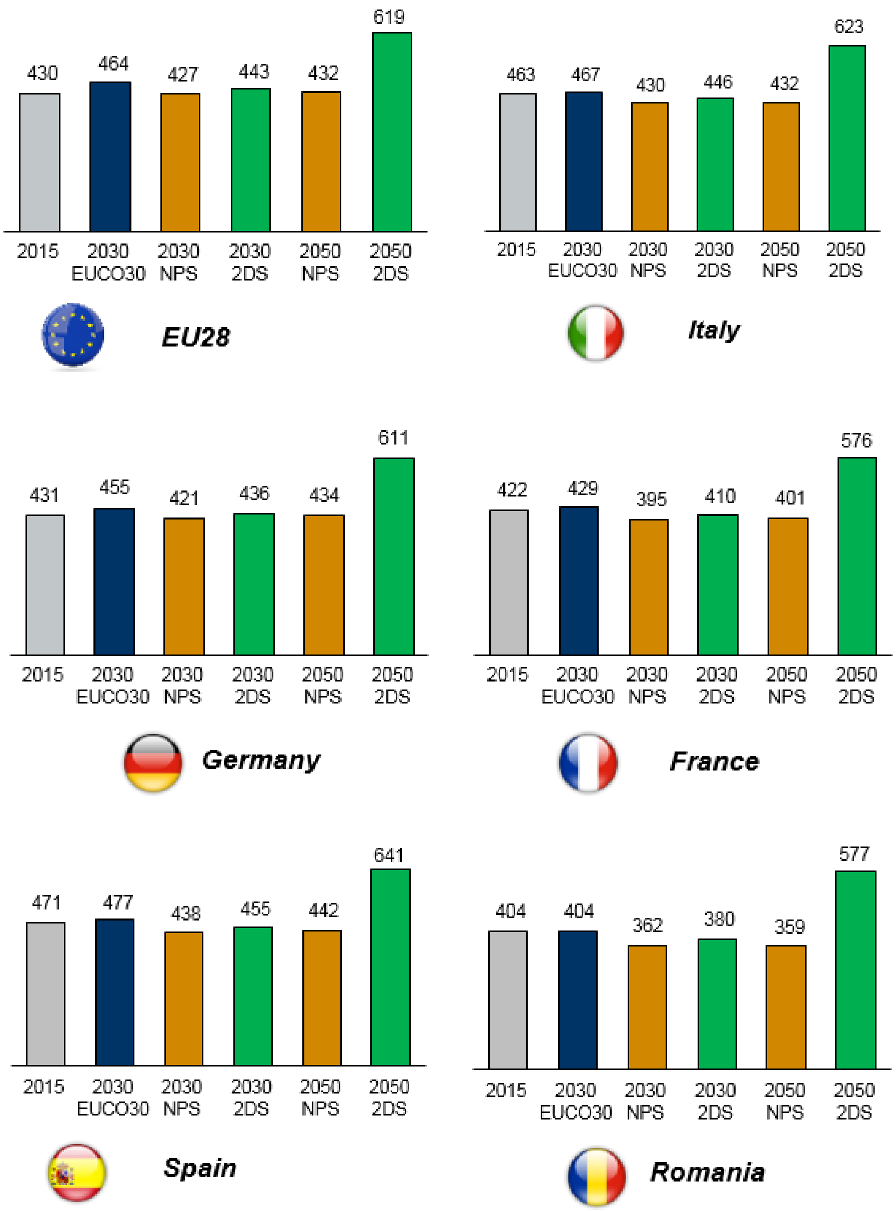
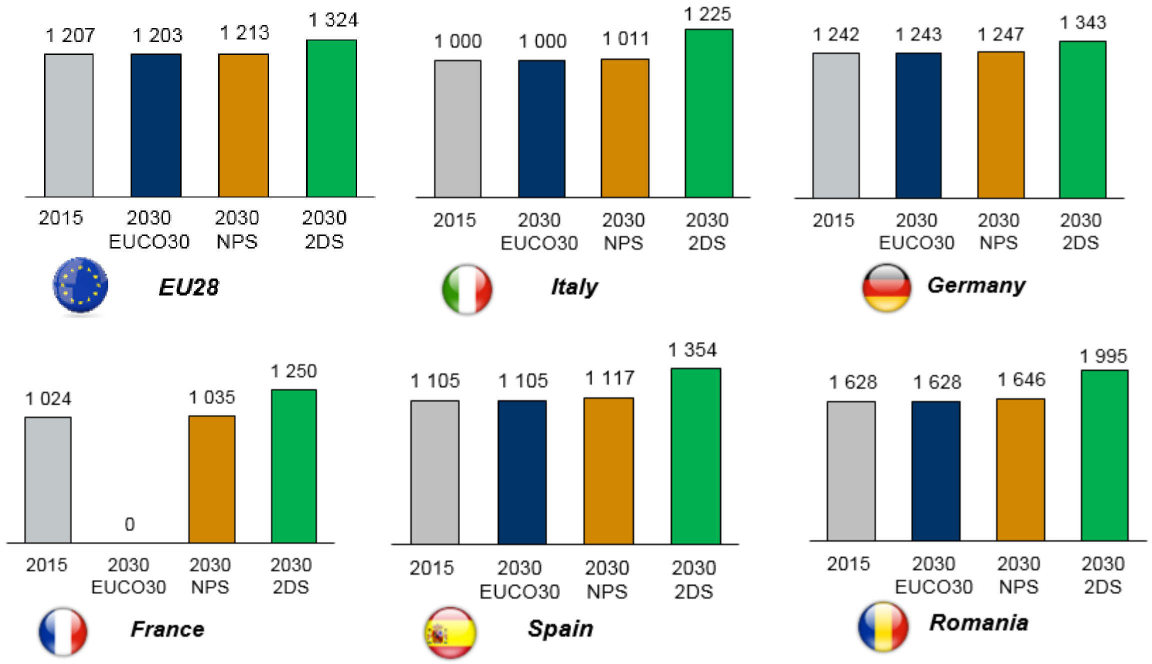


Figure 4-16 – NPS & 2DS Scenario in 2030: coal emission factors (gCO₂e/kWh) by geography



- 2030 results

In 2030, the analysis shows contrasting results for GHG emissions from CCGT vs. coal-fired power plants, depending on the scenario.

For the EU28 in the EUCO30 scenario, GHG emissions associated with coal-fired power plants still exceed those from CCGT natural gas power plants (579 Mt CO_2e vs. 207 Mt CO_2e). Emissions from coal significantly decrease in the NPS Scenario and even more so in the 2DS Scenario; where GHG emissions from coal-fired power plants are projected to be around 186 Mt CO_2e (vs. 276 Mt CO_2e from CCGT natural gas plants).

In the 2DS scenario, Romania is the only country where GHG emissions from coal are still projected to be larger than those from CCGT natural gas plants. This reflects the dominance of coal in the power mix for these two markets at the starting point. There are therefore lower opportunities for fuel switching.

With regard to the carbon emission factors, coal emission factors are the highest in the 2DS scenario, across all geographies considered in the study. This reflects the rapid fall in generation in this scenario, which is not matched by capacity retirements. This means plant utilisation falls drastically. This has a knock-on effect on efficiency, pushing emission factors up.

Natural gas CCGT emission factors are comparable between the scenarios and geographies, but slightly higher in the EUCO30 scenario, for all geographies.

- 2050 results

In 2050, the analysis shows a decrease in GHG emissions in both scenarios (NPS and 2DS).

In all geographies, no coal-fired plants are projected to be in operation in 2050 in all scenarios, thus resulting in zero emissions from coal. For the EU28, total emissions from CCGT natural gas plants are projected to be around 322 Mt CO_2e in the NPS Scenario, and around 70 Mt CO_2e in the 2DS Scenario.

For the projected carbon emission factors, natural gas emission factors are the highest in the 2DS scenario, for all geographies. At first, this is counter-intuitive. However, as for hard coal generation by 2030, natural gas generation falls much faster in the 2DS scenario, than in the NPS scenario. By 2050, across all geographies, natural gas generation load factor is as low as 3-6% in the 2DS scenario. In the NPS scenario, load factor is still 25% on average across all geographies. This means efficiency is much lower in the 2DS, and emissions factor correspondingly much higher.

This result reflects the different trajectories in power generation, considering the broad policy commitments and plans announced by the EU as set in the NPS scenario and the more substantial transition required to meet the trends set by the 2DS Scenario.

4.2.2 *TRANSITION: PROJECTED EVOLUTION FROM 2015 TO 2050*

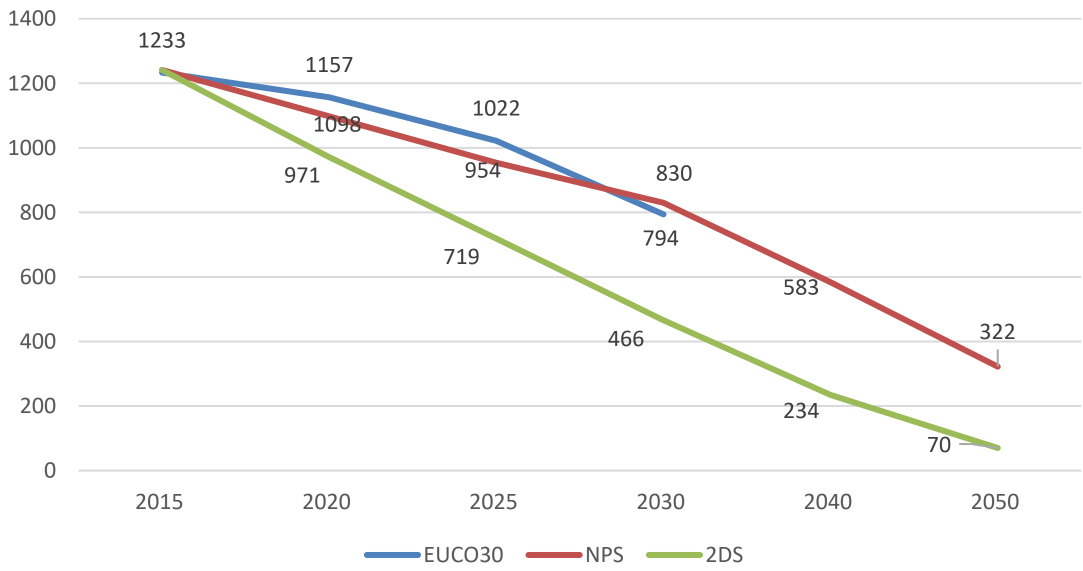
The projected evolution of total emissions between 2015 and 2050 is presented below for the EU28, for natural gas CCGT and coal-fired power plants.

Table 4.9 – Projected natural gas CCGT, hard coal, and lignite emissions (Mt CO_2e) for the EU28

	CCGT emissions (Mt CO_2e), EU28			Hard coal emissions (Mt CO_2e), EU28			Lignite emissions (Mt CO_2e), EU28		
Scenario	2015	2030	2050	2015	2030	2050	2015	2030	2050
EUCO30 (*)	243	207	*NA*	429	257	*NA*	539	322	*NA*
NPS	243	326	322	429	215	0	539	281	0
2DS	243	276	70	429	89	0	539	96	0

NOTE (*): EUCO30 projections at 2050 are not available.

Figure 4-17 – Projected upstream, midstream and downstream emissions (Mt CO_2e) for the EU28, natural gas CCGT, hard coal, lignite, and oil power generation combined



The European Commission had committed to reducing its greenhouse gas emissions by 40% below 1990 levels by 2030. In 1990, GHG emissions from energy (i.e. combustion and fugitive emissions) amounted to 4 341 $MtCO_2e$[1].

Please note that a direct comparison of these figures with the overall emissions from power generation as estimated in this assessment is not possible due to different boundaries and assumptions. Nevertheless, the potential for reduction in the power sector, for all scenarios considered, is clearly significant.

In 2030, the projected reductions in GHG emissions vs. the 2015 baseline are estimated to be larger than 30% when considering the EUCO30 and NPS scenarios (respectively 35% and 33%), and larger than 60% when considering the 2DS scenario. In 2050, the projected reductions in GHG emissions vs. the 2015 baseline are estimated to be larger than 70% when considering the NPS scenario, and larger than 90%, when considering the 2DS scenario.

[1] https://www.eea.europa.eu//publications/european-union-greenhouse-gas-inventory-2017

4.3 TRANSPORT SECTOR ANALYSIS (INTERNAL COMBUSTION VEHICLES VS. ELECTRIC VEHICLES)

The projected evolution over the time period 2015 to 2050 shows that electric vehicles outperform internal combustion vehicles due to lower overall GHG emissions of electricity versus fossil fuels.

The overall emissions per km from electric vehicles are expected to significantly decrease in all the scenarios considered and for all types of electric vehicle. In particular, the projected emissions in 2050 are expected to be less than half of those calculated in 2015, mainly due to a less carbon-intensive electricity supply.

4.3.1 2030

2030 results represent the projected situation at the 2030 time horizon considering fit-for-purpose scenarios developed based upon, respectively, (i) the EUCO30 Scenario, (ii) the NPS Scenario, and the (iii) 2DS Scenario. In particular, the 2030 transport sector analysis uses the results of the power sector analysis based on the EUCO30 Scenario, as appropriate, to ensure full alignment.

The following results are obtained by vehicle technology, broken down by life cycle stage, for segment C vehicles, considering an average consumption of electric vehicle as defined by the EMPA methodology followed. Upstream, midstream and downstream emissions are included. Biofuels content are 10% ethanol in petrol, 7% biodiesel in diesel and 10% biomethane in compressed natural gas. Differences in relative terms between the different vehicle technologies are bigger when considering RDE and NEDC conditions. In relative terms, the benefit in terms of GHG emission reduction of using an electric vehicle vs an internal combustion vehicle are higher when considering Real-Driving Emissions. In general, RDE emissions are higher for all technologies, and NEDC emissions are lower for all technologies.

Figure 4-18 – Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, in 2030 EUCO30 scenario, under WLTP conditions

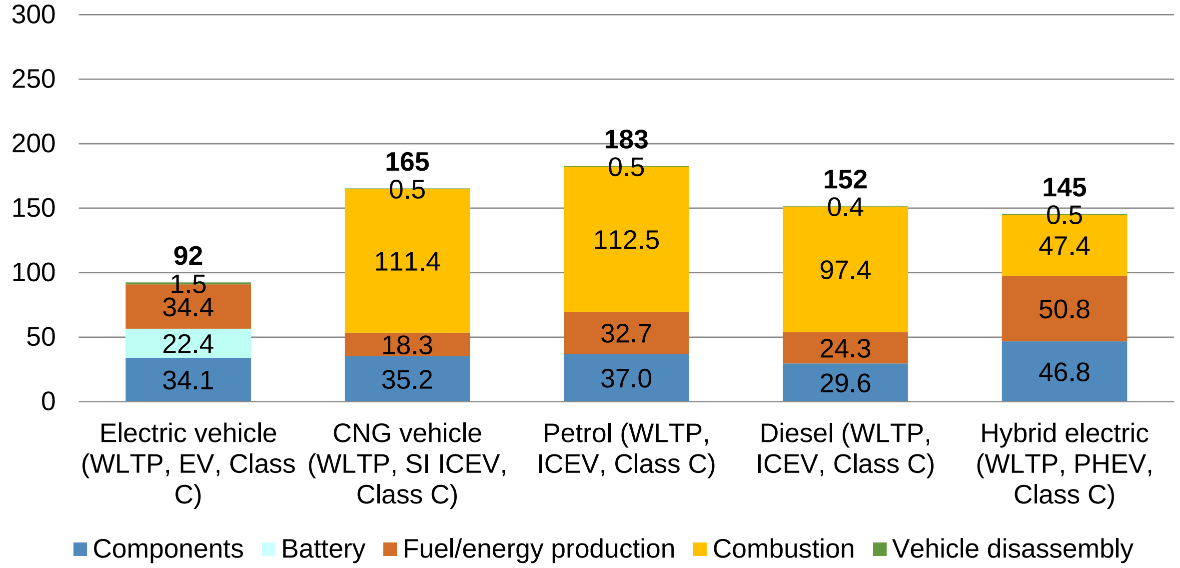
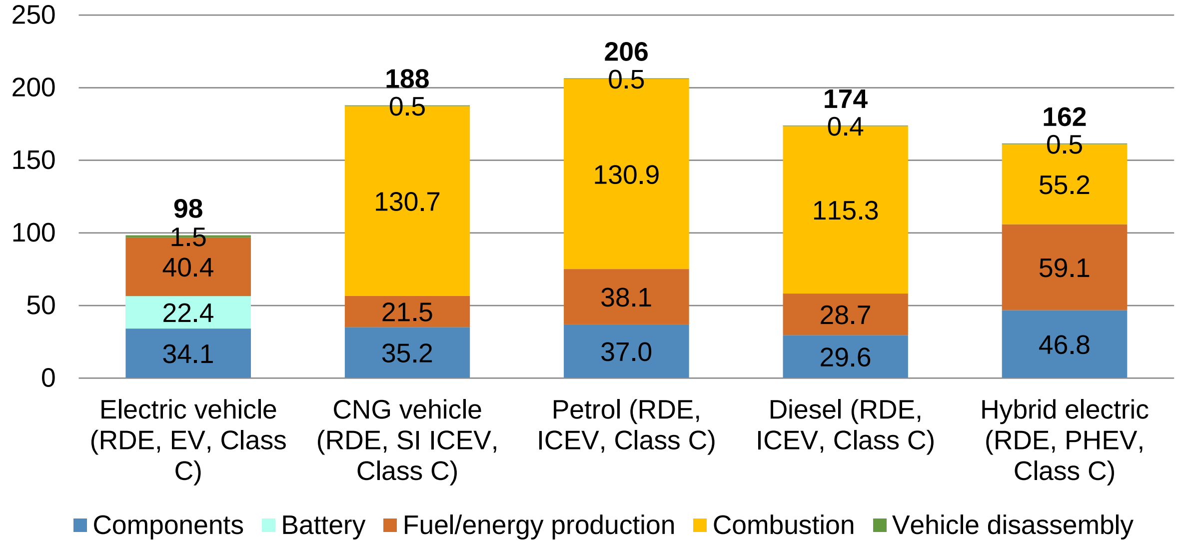


Figure 4-19 – Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, in 2030 EUCO30 scenario, under Real-Driving Emission conditions



By 2030, electric vehicles will further outperform other vehicles given the decarbonization trend in the power mix, for all scenarios considered and all geographies. By 2030, emissions of electric vehicles could decrease as average for the EU28 by ca. 30% in the EUCO30 scenario for instance, under WLTP conditions, and by ca. 33% under RDE conditions, when compared to the baseline.

Table 4.10 – Reduction of Electric Vehicles GHG emissions versus Internal Combustion Engine vehicles, in 2030 EUCO30 scenario

		CNG	PETROL	DIESEL	PHEV
WLTP Conditions	Well-to-Wheel: Electric vehicle vs.	-73%	-76%	-72%	-65%
	Well-to-Wheel + LCA: Electric vehicle vs.	-44%	-50%	-39%	-37%
RDE Conditions	Well-to-Wheel: Electric vehicle vs.	-73%	-76%	-72%	-65%
	Well-to-Wheel + LCA: Electric vehicle vs.	-48%	-52%	-43%	-40%

4.3.2 2050

2050 results represent the projected situation at the 2050 time horizon considering fit-for-purpose scenarios developed based upon, respectively, the NPS Scenario and the 2DS Scenario. In particular, the transport sector analysis has been fed with the results of the power sector analysis as appropriate to ensure full alignment.

The following results are obtained by vehicle technology, broken down by life cycle stage, for segment C vehicles, considering an average consumption electric vehicle as defined by the EMPA methodology followed. Upstream, midstream and downstream emissions are included. Biofuels content are 10% ethanol in petrol, 10% methane in compressed natural gas, and 7% biodiesel in diesel.

Figure 4-20 - Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, in 2050 NPS scenario, under WLTP conditions

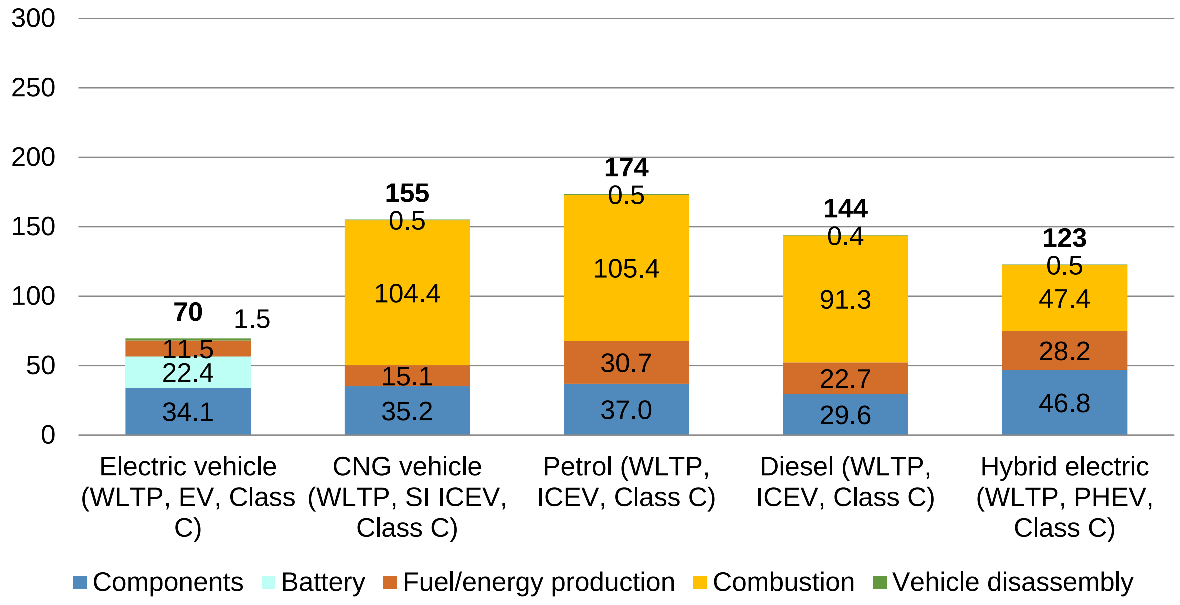


Figure 4-21 - Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, in 2050 NPS scenario, under Real-Driving Emission conditions

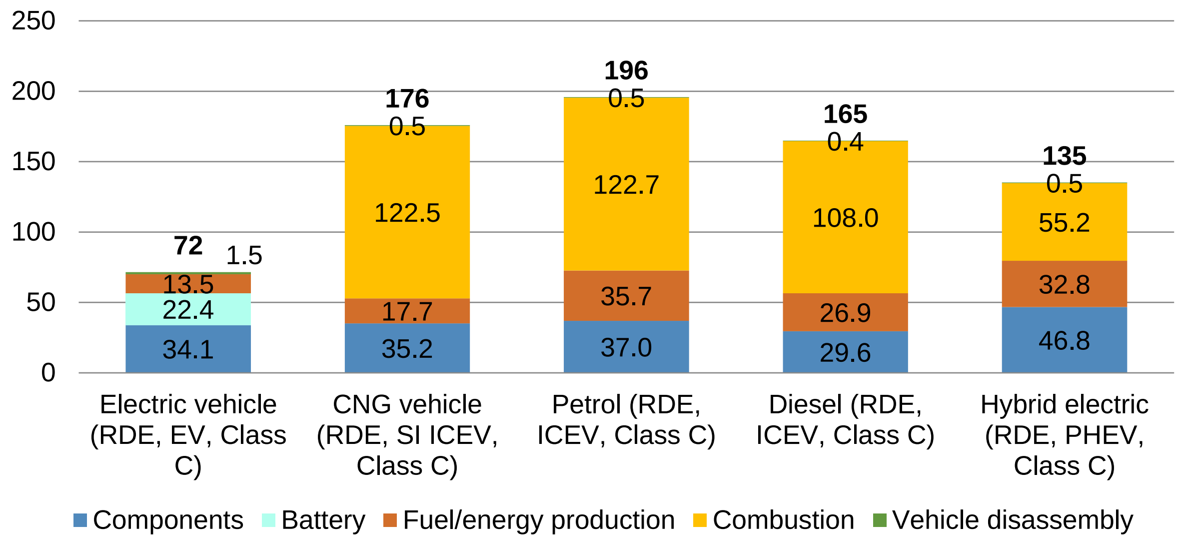


Figure 4-22 - Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, in 2050 2DS scenario, under WLTP conditions

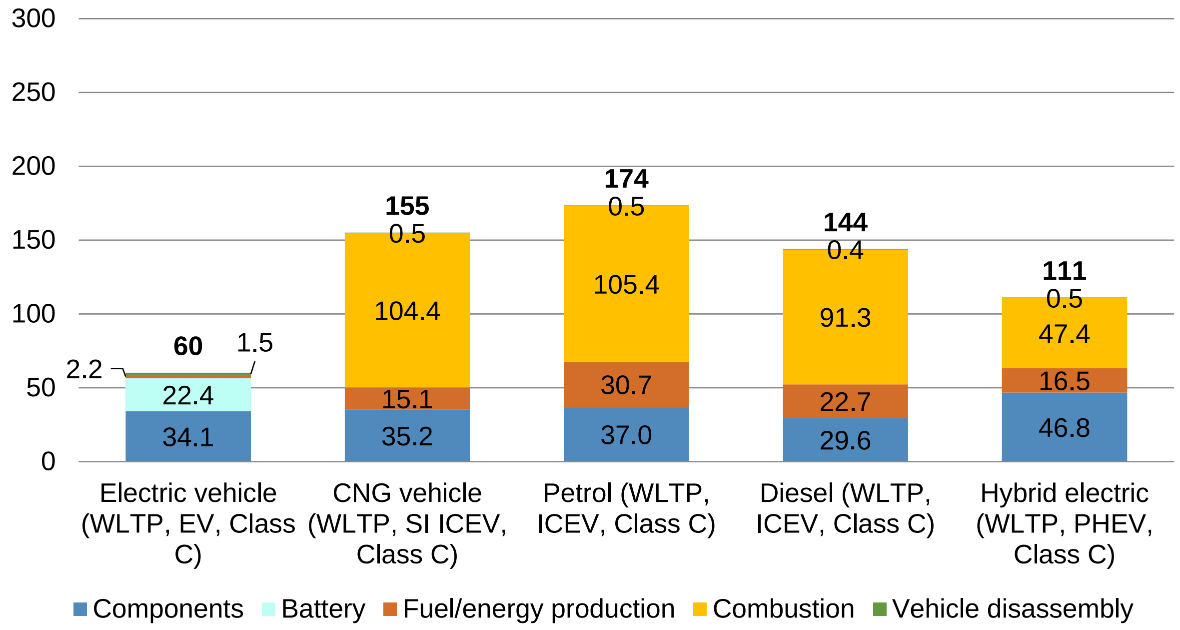


Figure 4-23 - Internal combustion vs. electric vehicle GHG emission factors (g CO_2e/km) by vehicle technology and by life-cycle stage, at EU level, under Real-Driving Emission conditions

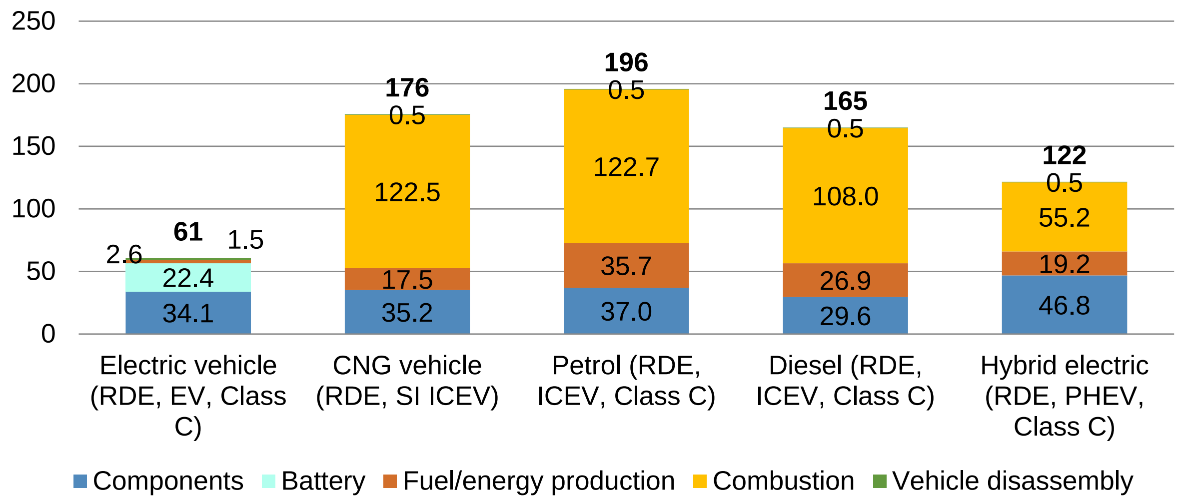


Table 4.11 – Reduction of Electric Vehicles GHG emissions versus Internal Combustion Engine vehicles, in 2050 NPS scenario

		CNG	PETROL	DIESEL	PHEV
WLTP Conditions	Well-to-Wheel: Electric vehicle vs.	-90%	-92%	-90%	-82%
	Well-to-Wheel + LCA: Electric vehicle vs.	-55%	-60%	-51%	-43%
RDE Conditions	Well-to-Wheel: Electric vehicle vs.	-90%	-92%	-90%	-82%
	Well-to-Wheel + LCA: Electric vehicle vs.	-59%	-63%	-56%	-47%

Table 4.12 – Reduction of Electric Vehicles GHG emissions versus Internal Combustion Engine vehicles, in 2050 2DS scenario

		CNG	PETROL	DIESEL	PHEV
WLTP Conditions	Well-to-Wheel: Electric vehicle vs.	-98%	-98%	-98%	-97%
	Well-to-Wheel + LCA: Electric vehicle vs.	-61%	-66%	-58%	-46%
RDE Conditions	Well-to-Wheel: Electric vehicle vs.	-98%	-98%	-98%	-97%
	Well-to-Wheel + LCA: Electric vehicle vs.	-65%	-69%	-63%	-50%

By 2050, electric vehicles will greatly outperform other vehicles given the decarbonization trend in the power mix, for all scenarios considered and all geographies. EVs will emit in the range of 60-70% less GHG emissions than ICEs for the scenarios considered, from an overall perspective, and up to 98% less if only energy-related emissions are considered.

4.3.3 TRANSITION: PROJECTED EVOLUTION OVER THE TIME PERIOD 2015 - 2050

The projected evolution over the period 2015 to 2050 is presented below by vehicle technology for the C-segment, in terms of overall emissions.

Table 4.13 – Projected evolution over the time period 2015 to 2050: electric vs. internal combustion vehicle GHG emission factors (g CO_2e/km) by vehicle technology, under WLTP conditions, EU28

Vehicle technology	2015 Baseline, Total (gCO_2e/km)	2030, Total (gCO_2e/km)	2050, Total (gCO_2e/km)
Battery Li-Ion, EMPA EV, EUCO30	132.1	92.4	NA
Battery Li-Ion, EMPA EV, NPS	132.1	94.0	69.5
Battery Li-Ion, EMPA EV, 2DS	132.1	79.0	60.2
CNG vehicle (SI ICEV)	215.0	165.3	155.2
Petrol (ICEV class C)	218.9	182.7	173.6
Diesel (ICEV class C)	182.0	151.6	144.0
Hybrid electric (PHEV class C), EUCO30	169.3	145.5	NA
Hybrid electric (PHEV class C), NPS	169.3	147.2	122.8
Hybrid electric (PHEV class C), 2DS	169.3	131.0	111.2

Figure 4-24 – Projected evolution over the period 2015 to 2050: electric vs. internal combustion vehicle GHG emission factors (g CO_2e/km) by vehicle technology – NPS scenario, under WLTP conditions, EU28.

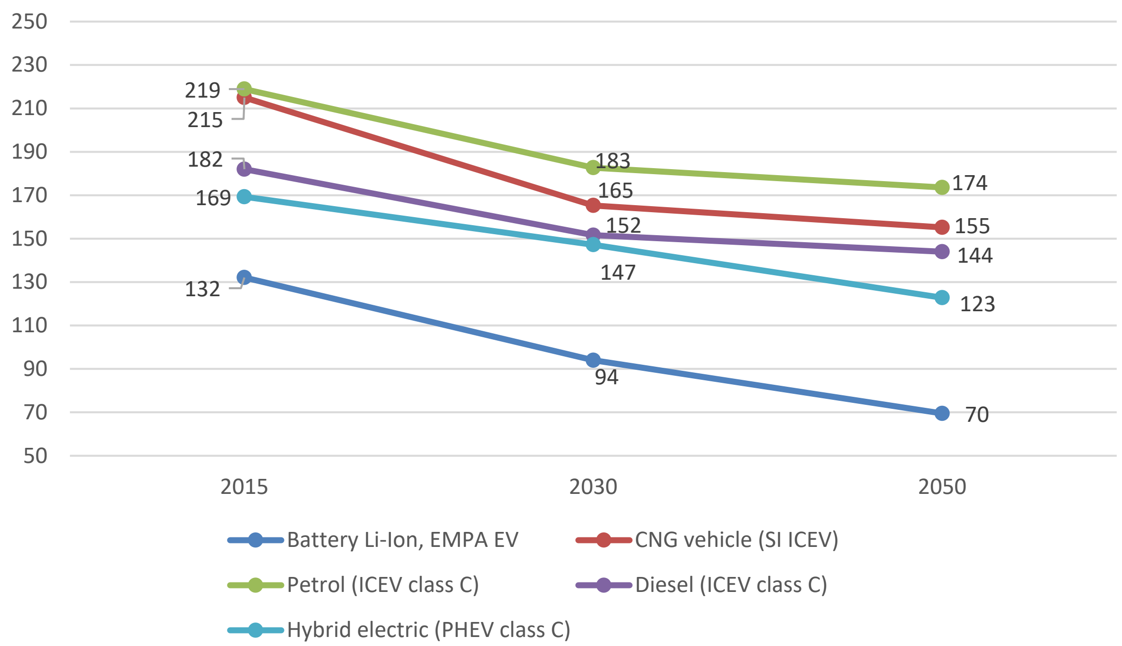
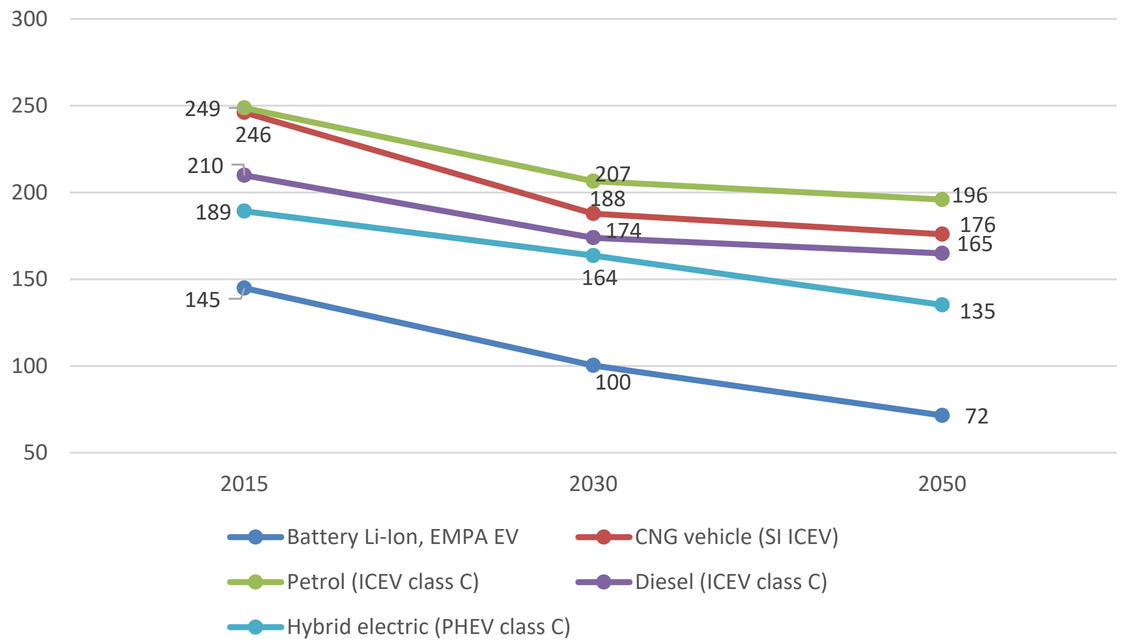


Table 4.14 – Projected evolution over the period 2015 to 2050: electric vs. internal combustion vehicle GHG emission factors (g CO_2e/km) by vehicle technology, under RDE conditions, EU28

Vehicle technology	2015 Baseline, Total (gCO_2e/km)	2030, Total (gCO_2e/km)	2050, Total (gCO_2e/km)
Battery Li-Ion, EMPA EV, EUCO30	144.9	98.4	NA
Battery Li-Ion, EMPA EV, NPS	144.9	100.3	71.5
Battery Li-Ion, EMPA EV, 2DS	144.9	82.7	60.6
CNG vehicle (SI ICEV)	246.1	187.8	175.9
Petrol (ICEV class C)	248.7	206.5	195.9
Diesel (ICEV class C)	209.9	173.9	164.9
Hybrid electric (PHEV class C), EUCO30	189.2	161.6	NA
Hybrid electric (PHEV class C), NPS	189.2	163.6	135.2
Hybrid electric (PHEV class C), 2DS	189.2	144.8	121.7

Figure 4-25 – Projected evolution over the period 2015 to 2050: electric vs. internal combustion vehicle GHG emission factors (g CO_2e/km) by vehicle technology – NPS scenario, under RDE conditions, EU28.



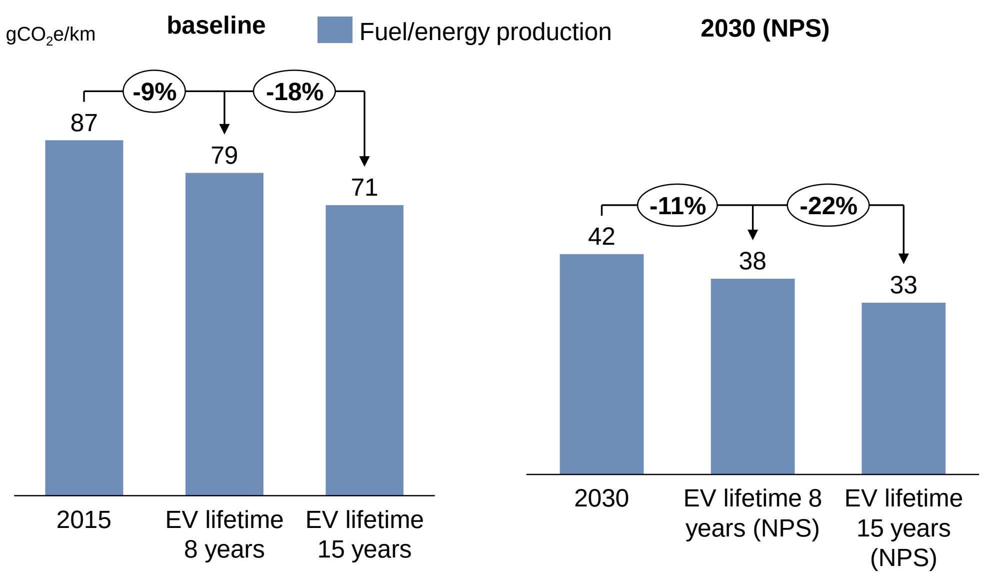
The projected evolution over the period 2015 to 2050 shows that electric vehicle outperforms internal combustion vehicles due to lower overall GHG emissions of electricity versus fossil fuel overtime.

The overall emissions per km from electric vehicles are expected to significantly decrease in all the scenarios considered, and for all types of electric vehicle. In particular, the projected overall emissions in 2050 are expected to be less than half of those calculated in 2015, mainly due to a less carbon-intensive electricity supply. If only emissions related to the electricity supply are considered, in the period 2015-2050 GHG emissions of electric vehicles fall down between 85% and 98% depending on the scenario.

4.3.4 *SENSITIVITY ON ELECTRIC VEHICLE LIFETIME*

With regard to electric vehicle lifetime, the study shows that if a 8- or 15- year lifetime of electric vehicles is considered, the energy related CO_2 emissions of the whole period further decrease by 9% and 18% respectively from 2015 on, thanks to an ever-increasing penetration of renewable energy sources in Europe. If instead a 2030 European EV is considered, its emissions will decrease on average 11% and 22% considering respectively an 8- year lifetime and a 15- year lifetime under the NPS scenario. In practice, this indicates that the on-going decarbonization of the electricity system provides increased GHG emission reduction overtime for electric vehicles owners.

Figure 4-26 – Sensitivity analysis of electric vehicle lifetime, at EU 28 level, considering real driving emissions conditions (g CO_2e/km)



5 *ANNEX A – GLOSSARY*

CCGT: Combined Cycle Gas Turbine

CNG: High pressure natural gas

EC: European Commission

EMPA: Swiss Federal Laboratories for Materials Science and Technology

ENTSOE: European Transmission System Operators for Electricity

EU: European Union

EUCO30: European Commission 2030 Scenario

EV: (battery) Electric Vehicle

GHG: Greenhouse Gases

GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation life cycle model

IEA: International Energy Agency

JRC: Joint Research Centre (European Commission)

LCA: Life-Cycle Assessment

LNG: Liquefied Natural Gas

NEDC: New European Driving Cycle (introduced in 1997)

NPS: New Policies Scenario

PHEV: Plug-in Hybrid Vehicle

RDE: Real Driving Emission conditions

SI HEV: Spark-Ignition Hybrid Electric Vehicle

SI ICEV: Spark-Ignition Internal Combustion Engine Vehicle

TTW: Tank to Wheel

WEO: World Energy Outlook

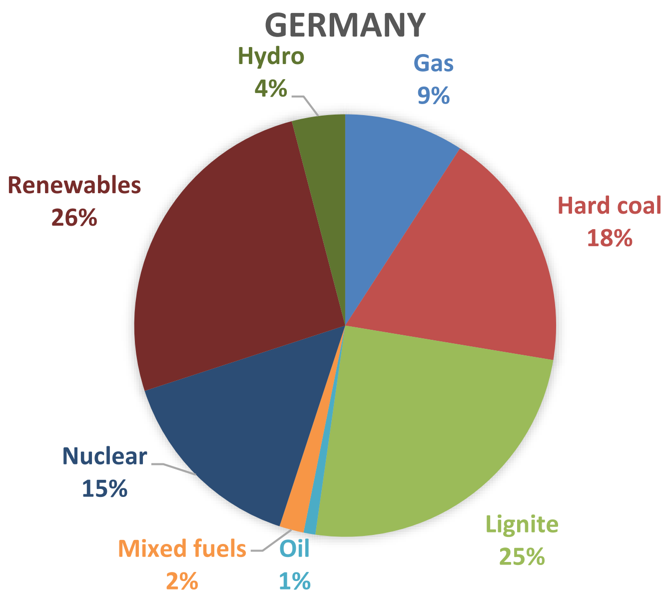
WLTP: Worldwide harmonized Light Vehicles Test Procedure (introduced in 2018)

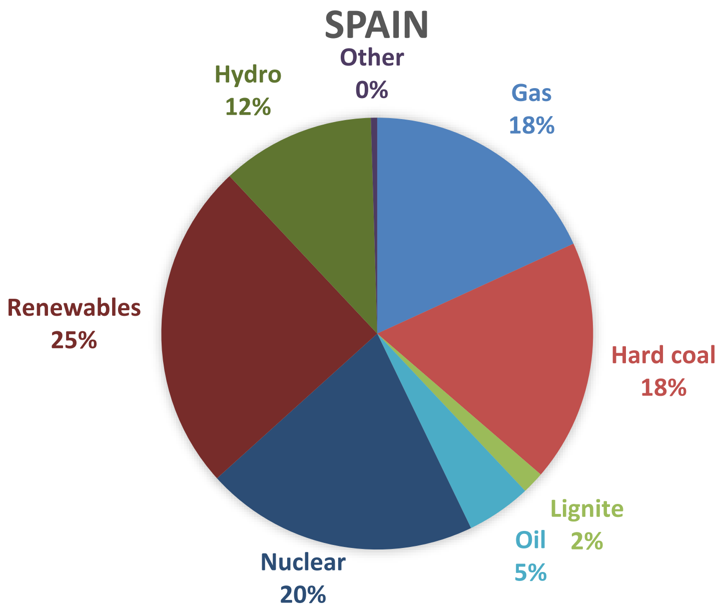
WTW: Well to Wheel

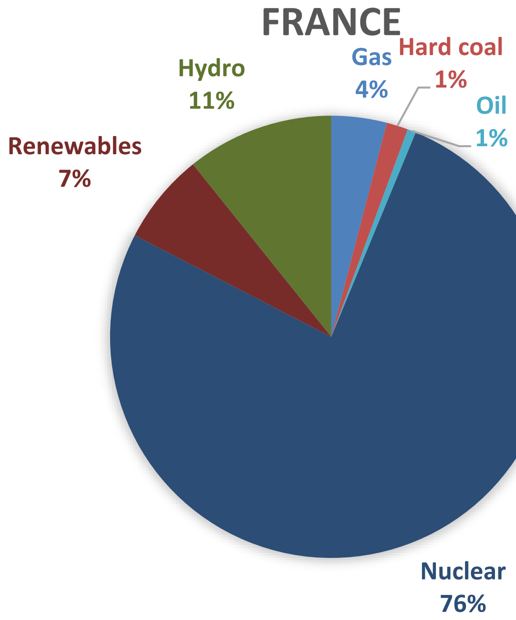
2DS: 2°C Scenario

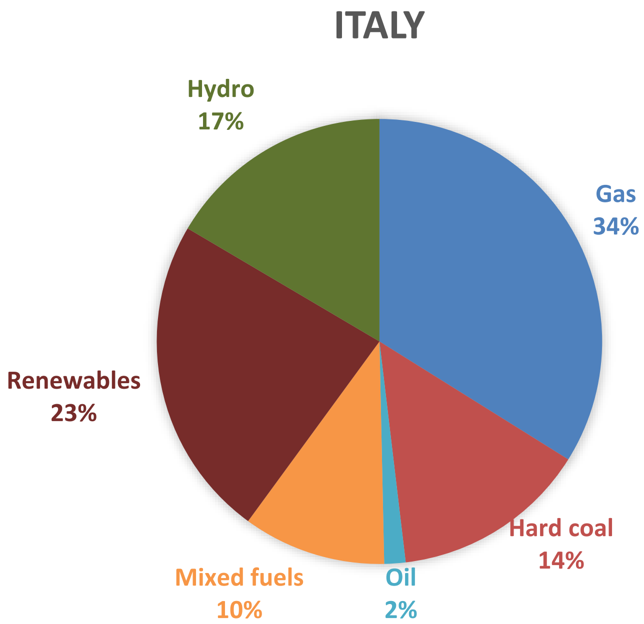
Additional graphs, as taken from the Excel tool, are included below to provide more information on the evolution of power generation, the generation mix and the transport projections in the covered geographies according to the different scenarios considered in this assessment.

Figure 6-1 – Power generation mix by country, 2015






FRANCE
Gas
4%
Hard coal
1%
Oil
1%
Hydro
11%
Renewables
7%
Nuclear
76%


ITALY
Hydro
17%
Gas
34%
Renewables
23%
Hard coal
14%
Mixed fuels
10%
Oil
2%

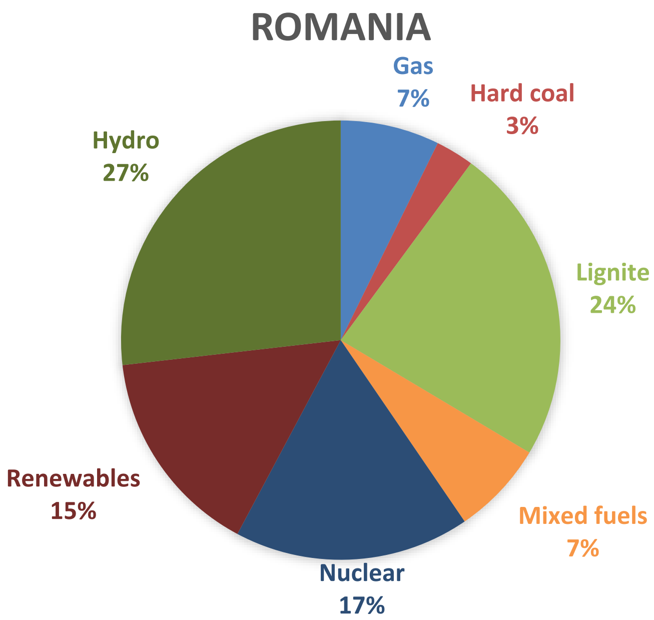


Figure 6-2 – Total generation (TWh) at EU level by 2030 and 2050, by scenario

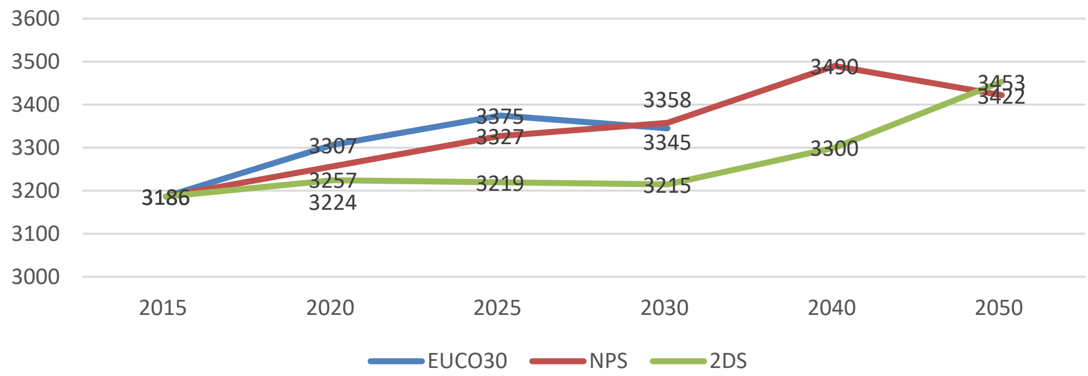


Figure 6-3 – Evolution of the generation mix (TWh) at EU level, by scenario

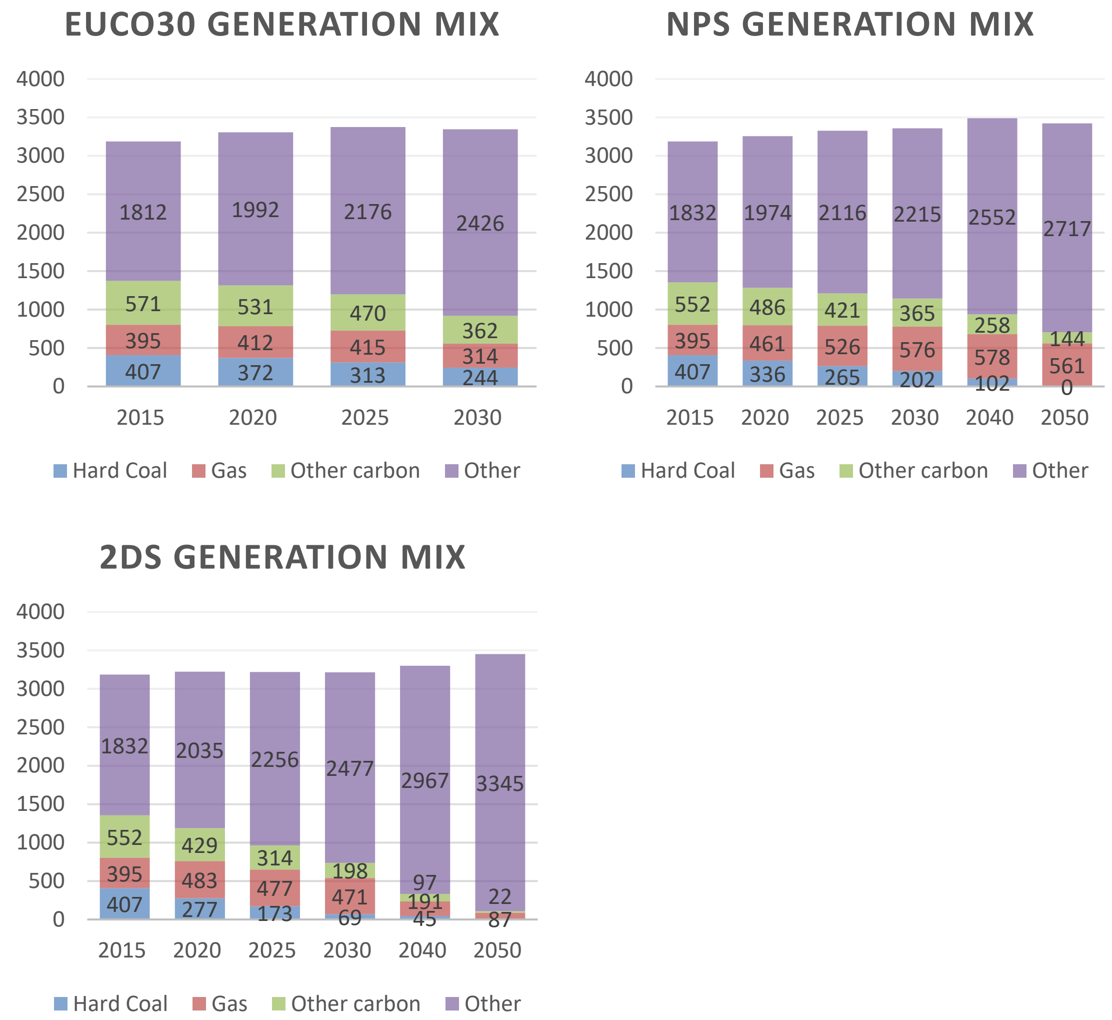


Figure 6-4 – Evolution of the overall GHG emissions of EVs (g CO_2e/km), by scenario

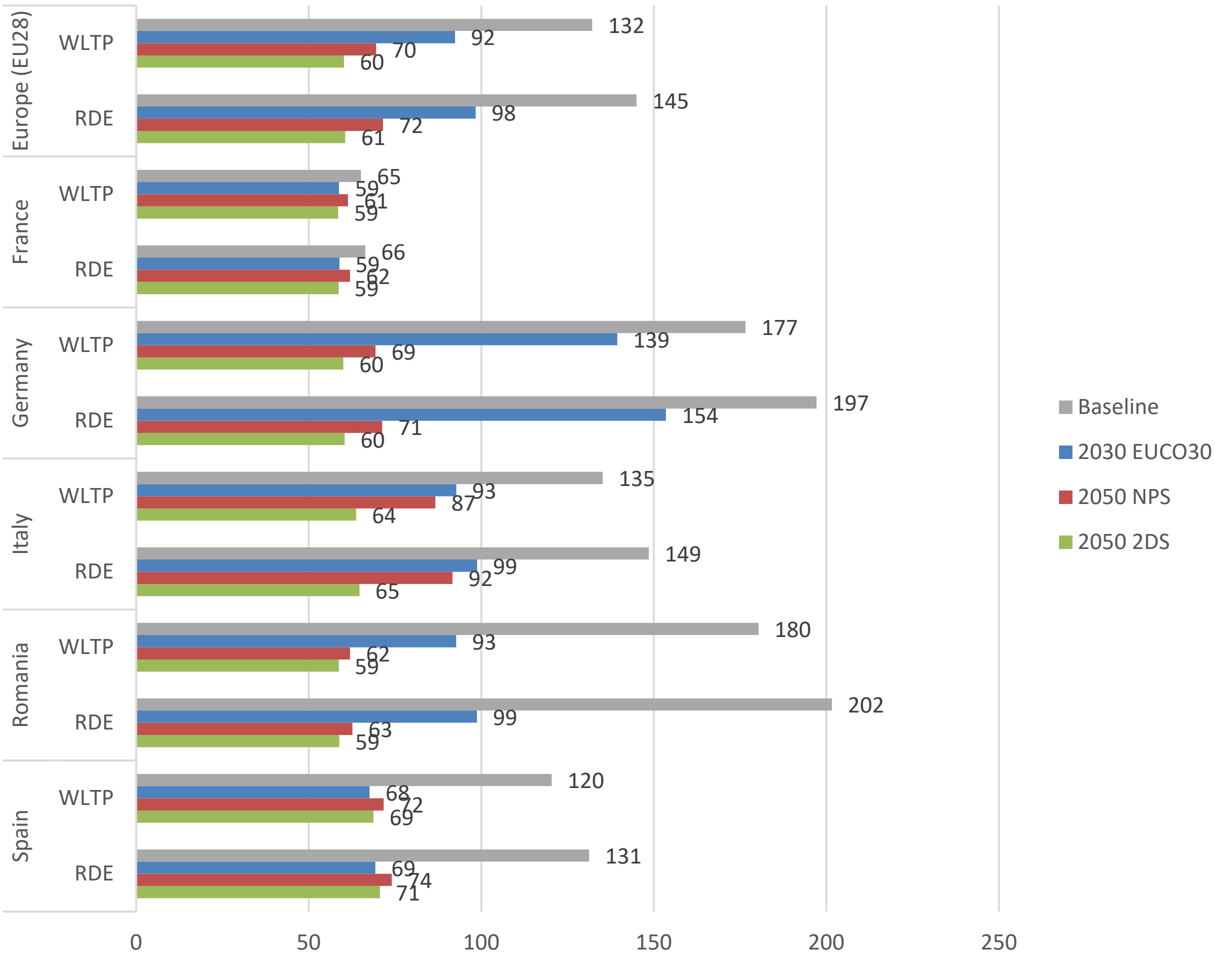


Figure 6-5 – Evolution of the fuel/energy production GHG emissions of EVs (g CO_2e/km), by scenario

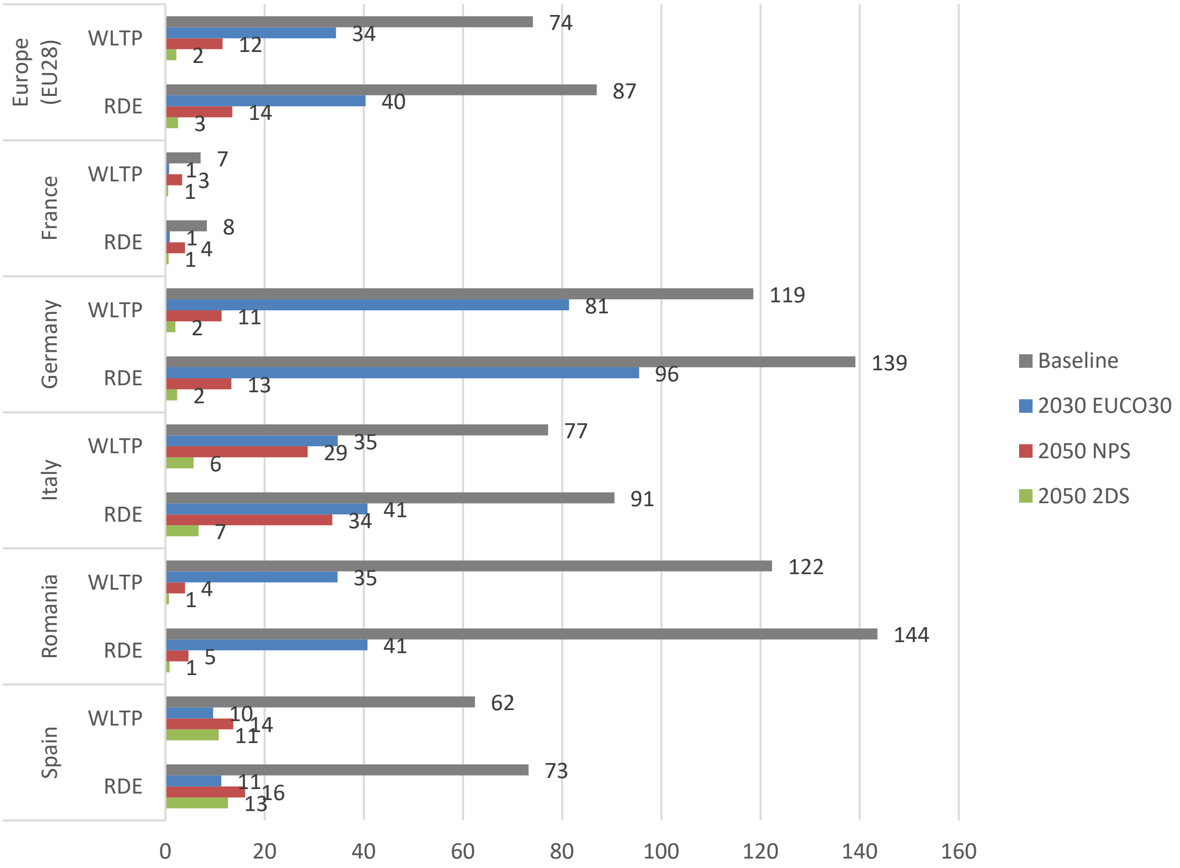


Figure 6-6 – Evolution of the fuel/energy production GHG emissions of CNG vehicles (g CO_2e/km), by scenario, RDE

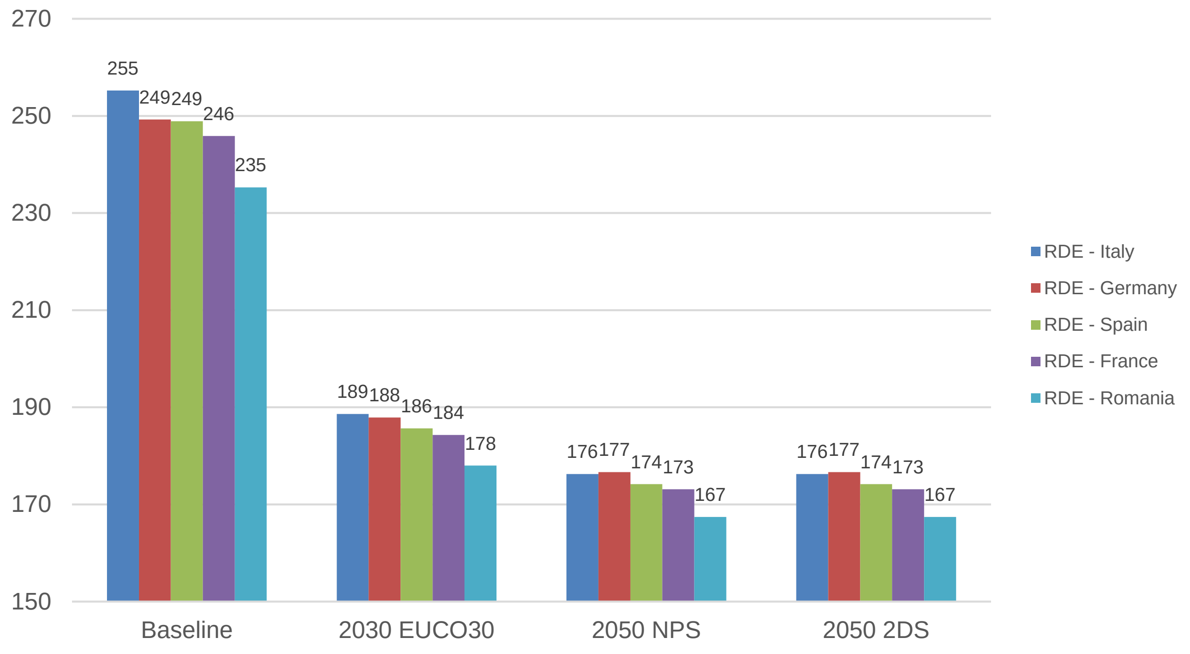


Figure 6-7 – Evolution of the overall GHG emissions of PHEVs (g CO_2e/km), by scenario

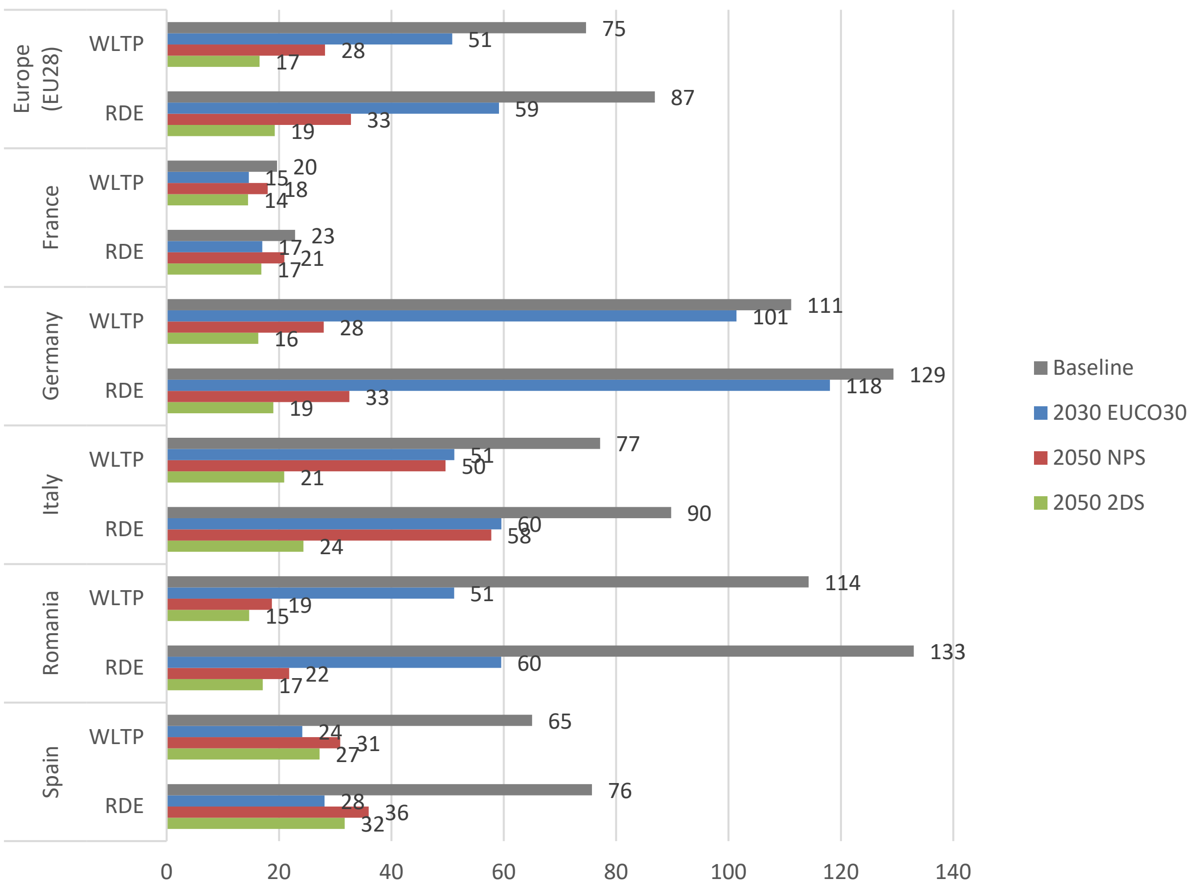


Figure 6-8 – Evolution of the fuel/energy production GHG emissions of PHEVs (g CO_2e/km), by scenario