MSc Program
Renewable Energy Systems

Sustainable development of the public transport sector in EU Countries

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
Dipl.-Ing. Dr. Amela Ajanovic

BSc Anastasia Ciura

11728345

Vienna, 24.11.2019

Affidavit

I, **BSC ANASTASIA CIURA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "SUSTAINABLE DEVELOPMENT OF THE PUBLIC TRANSPORT SECTOR IN EU COUNTRIES", 77 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 24.11.2019

Signature

Table of contents

Abstract

Nowadays, global warming and climate change are often recurrent topics of discussion.

Average global temperatures have risen significantly in recent decades: today, there is an increase of 0.85 ° C compared to the end of the nineteenth century. Scientists consider a 2°C increase over pre-industrial levels as a threshold with dangerous and catastrophic consequences for the climate and the environment.

For this reason, the international community agrees that global warming must remain well below a 2°C increase.

According to the European Environment Agency (EEA), the EU is the third-largest producer of GHG's in the world after China and the United States. For this reason, the EU starts launching several strategic plans and environmental and energy frameworks to mitigate Climate Change by reducing GHG emissions.

As a result of the several environmental measures and restrictive policies, the EU-28 achieved in 2017 a reduction of 22 % of the total GHG emissions compared with 1990 levels. However, GHG emissions caused by the transport sector have increased over the past five years, mainly due to the economic growth and the increase in activity levels, despite the improvements in energy efficiency and advanced technologies in the sector.

Several commitments and strategies focused on different areas of the whole transport sector, such as the White Paper, were implemented by the European Commission (EC) with the purpose of monitoring and reduce GHG emissions by 60 % compared to 90's levels, by 2050.

This work highlights the fundamental role of the public transport sector into the EU, as a backbone of the sustainable mobility system for the development of a unified market. It represents the crucial means to reach the objectives set from EC.

This work focuses on the primary sources of increase in GHG emissions in the transport sector: road and aviation emissions.

Two core objectives are considered, with a focus on the public transport sector: the replacement of the diesel city buses with electric (EBs) and hydrogen fuel cell buses (HFCBs) and the substitution of domestic and intra-EU flights with high-speed power trains.

The replacement of the current DBs with cleaner fuels and alternative technologies could decrease the air and noise pollution significantly in a city. While the use of power trains, through the commissioning of the high-speed rail (HSR) infrastructure across Europe, could represent a significant saving in travel time and emissions.

In this context, the EU supports the implementation of the TEN-T project, which includes the construction of an extensive HSR network.

It comprises two "levels" of network: the core network, which provides the connection between the busiest European nodes by 2030 and the extensive network, which covers all European regions by 2050.

The outcome of the two cases of studies described a comparative analysis in terms of environmental impacts, costs, and several potential benefits as in efficiency and performance.

The results show that the environmental impact would be zero-emission in both cases of studies, but the investment is still higher, mainly due to the immaturity of the technologies and missing infrastructures.

The sustainable development of the whole transport sector must be accompanied by the development of new transport infrastructure and clear working guidelines applied by each Member States.

In this scenario, technological advancement in the field of renewable energy plays a crucial role in pursuing the objective of providing efficient and sustainable solutions to neutralize and mitigate the current environmental situation.

1. Introduction

The transport sector is a cornerstone of European integration and is firmly linked to the establishment of a single European market, with fair competition conditions for and between the different forms of transport: road, rail, air and waterborne.

If one of the main objectives of the EU is to achieve a further unified European market through efficient transport, this step forward must occur in a sustainable path.

The electrification of the end-use sectors is considered in an international context by climate change policymakers as a strategy to drive decarbonization.

Shifting from carbon-intensive feedstocks to electricity could significantly reduce GHG emissions only if the power generation is obtained from low-carbon sources.

The question about how to balance the increasing demand for electricity often arises. The electrification of end-use sectors like transportation is an actual topic of discussion in the energy sector, and it has several drivers.

The development of advanced technologies can support the shift towards a more sustainable and environmental benign transport system. Transport system in the EU-28, relying on three main pillars: the use of low-carbon energy, increase vehicle efficiency through the development of new engines and materials and investing in new interconnecting infrastructures

Based on these three factors, the integration of more environmentally benign technologies will be forced, without focusing all efforts into electrification as a solution within the whole transport system.

Nowadays, the EU has implemented incentives for low-carbon renewable energy carriers and vehicles. Moreover, it has encouraged the use of alternative fuels for public transport such as for the buses in town and coaches and invested in new infrastructures in-EU Countries, as TEN-T core network.

It is an ambitious project aimed to build an active EU-wide transport infrastructure network. It includes the construction of a dense rail network between major European cities, with the scope to increase the use of high-speed power trains and decrease the domestic air flights between the neighboring European capitals. It would enable high-speed train connections to become real alternatives to flights within the big metropolis in the EU countries, generating a substantial reduction in emissions.

However, cities and local authorities will play the most crucial role in delivering this low-emission strategy.

Municipalities have to take cost-effective decisions based on limited budgets respecting their local pollution reduction targets.

The shift from ICEs (internal combustion engine) to electric and alternative fuels could represent the beginning of a new era regarding urban mobility. The new infrastructure and the time needed to build it, represent a significant step forward within this transition.

Emissions from the road public transport sector could be brought back to the '90s levels in 2030. The road public transport sector can be optimized working through restrictive measures and affordable pricing schemes to tackle congestion and air pollution.

The continuous transition towards a broader penetration of low carbon vehicles in all transport modes, including plug-in hybrids and electric vehicles (EVs, BEVs, powered by batteries or fuel cells FC), and hybrid engine technologies, can be supported by enhanced efficiency and more demand-side management, fostered through CO2 standards and effective taxation systems at a later stage.

Europe's automotive industry is also looking for solutions with alternative fuels and propulsion methods to take care of environmental objectives such as improved air quality in cities through the reduction of oil dependence. Within this topic, it is not surprising to see also oil & gas companies and automotive industries increasing their investments in future energy and new technologies. (OMV, 2019), AUDI automotive industry is supporting a Bio-methane project provided by the University of Zurich, and many other companies have started to develop benchmarks and roadmaps for different technology segments in this direction.

It is, therefore, necessary to consider several types of technologies, taking into account the time needed for the construction and the implementation of new infrastructures and the related systems technology that every metropolis needs to pursue to ensure this change taking place.

1.1 Core objectives of this work

This work intends to provide insight into possible actions to achieve a significant reduction in GHG emissions to meet the corresponding policy targets, starting from existing European policies and initiatives related to the transport sector.

The core objective of this paper is to analyze how a sustainable development of public transport in Europe can be achieved — focusing on two main topics: city bus transport and short-haul flights among the biggest European cities.

These two topics are described through a comparative analysis between diesel (ICE), electric, and fuel-cell hydrogen city buses, in terms of emissions and environmental impacts.

In regards to the total costs for each bus technology considered, it was carried a Life Cycling Cost (LCC) analysis.

As expected, the outcome shows the lower cost for the diesel buses comparison with the other technologies, taking into account the costs of purchasing, maintenance, and fuelling or recharging.

The HSTs show higher savings in terms of CO2 emissions and fuel consumption compared to the aircraft means.

In addition, a comparative study was conducted based on three major European routes: Rome – Milan, London – Paris, and Madrid – Barcelona.

These are cities that provide an efficient high-speed rail (HSR) connection, in addition to the regular airborne operated by low and no-low-cost airlines.

For this reason, it was possible to compare the two modes of transport in terms of travel time, frequency, and return fare when purchasing train/flight tickets in two different timeframes (one week before departure compared to three months before).

1.2 Method of approach

In this paper, different methods of approach are applied over the different chapters.

The GHG emissions and European transport statistics were addressed by the EEA and pocketbooks provided by Eurostat, an institution that collects and describes the most essential features of transport, in terms of the quantities of passengers that are moved each year, number of vehicles and infrastructure were used as primary data sources in sections two and three.

The major initiatives and future strategies were introduced based on the public statements on the European Commission website to address the current political status-quo on the transport in Europe. Directives, policies and latest commitments have been taken from the official journal (OJ) of the European Union (https://eur-lex.europa.eu/).

Focusing on the two cases of study "City Buses by Diesel, Electric and Hydrogen Fuel cell" and “Economical and Timing comparative assessment between flight and high-speed train," a mix of quantitative and qualitative approaches have been applied. For the quantitative approach, data from scientific papers (e.g., Refs. M.Prussi, Laura Lonza 2018) have been reviewed. For the qualitative analysis, comprehensive literature on the has been reviewed (ITF, 2019).

The city-bus study is explored through a comparative analysis of three technologies: diesel, electric (BEV), and hydrogen fuel cell (HFCV).

The assessment is carried out from an economic and environmental point of view for each technology.

Concerning the economic assessment, a total cost of ownership (TCO) analysis through a life cycle cost (LCC) approach was performed for the three city bus technologies.

LCC is a structured approach of calculation that takes into account the purchasing price, energy consumption, operational cost (e.g., maintenance, cost of upgrades).

A Life-Cycle assessment (LCA) regarding the environmental impact was carried out. This analysis can be broken down in three stages, well to a tank (WTT) and tank to wheel (TTW), whose combination provides the complete picture for a well to wheel (WTW) analysis.

The first term, WTT, considers the energy costs of the energy carriers, their costs of extraction, exploitation, transportation, processing, and delivery.

The approach of TTW refers to the fuel intensity of the vehicle itself.

That means how much fuel is consumed until it is converted into mechanical energy and heat.

Moreover, regarding the electric vehicles such as buses and high-speed trains (HSTs) and hydrogen (with electricity as the primary feedstock for the electrolysis), an important factor considering power generation has to be pointed out.

Although electric vehicles (EVs) compared to conventional internal combustion engines (ICEs), may have "zero" emission at the point of use, their overall environmental benignity is highly dependent on primary energy sources used for electricity generation.

All environmental benefits of powertrains, FCH, and HS trains could be obtained just if the electricity used in means of transport is generated from renewable energy sources depending on the EU country that it is considered (Agora, 2018).

On this basis, a comparative environmental assessment related to the emissions caused by aircraft and high-speed rail train (HS-T) on the main European city-pairs, has been carried out, in which the essential result is a saving of 93% in CO2 emissions related the rail transport.

Besides, an economical and time analysis was carried out based on data collected from online travel agencies (e.g., google flights, Trenitalia, Eurostar) whose results in terms of frequency, costs, and travel times were presented in a comparative table.

1.3 Structure of work

The work is organized as follows, in the next chapter, information on the historical development of the GHG emissions development and EU-wide progress towards meeting its targets in reducing emissions are provided. Furthermore, the current EU policies and directives related to the transport sector are described in detail.

Chapter 3 highlights the overall development of road, rail, and aviation transport sector in the timeframe 1990-2016 through statistical data provided by the Statistical Pocketbook 2018.

Section 4 describes the ICE, EV, FCHV bus technologies through a comparative analysis in terms of costs, technology, and environmental aspects.

In chapter 5 is carried on a comparative assessment between HST and aviation means of transport. The economic and time comparative analysis is based on three main routes Madrid - Barcelona, Paris - London, and Rome - Milan, where high-speed trains are already a reliable means of transport, making feasible the comparison with air flights while the energy performance and environmental assessments are based on data published by Eurostar and Trenitalia.

1.4 Major Literature

A literature review is executed for the City bus and Aviation vs. HST case of studies. For the comparison of the three typologies of city buses (EB, HFCB, and DB), an LCC and an LCA analysis was carried out. The LCC calculation for DBs, EBs are based on the articles "*Comparison of the Lifecycle Cost Structure of Electric and Diesel Buses*" (Potkány M., 2018) and "*Dissemination of electric vehicles in urban areas: Major factors for success*" (Ajanovic A., 2016).

The HFCB LCC was assessed according to the following articles in "*Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe*" (Berger, 2015) and in "*On the economics of hydrogen from renewable energy sources as an alternative fuel in the transport sector in Austria.*" (Ajanovic, 2008)

For the environmental assessment, two articles of various authors are used to establish the theoretical base: "*Performance comparison of conventional, hybrid, hydrogen and electric urban buses using well to wheel analysis*" (Correa G., 2017) and "*a tank-to-wheel analysis tool for energy and emissions studies in road vehicles*" (Silva C.M., 2006).

For the aviation and HST study, the scientific papers reviewed are: "*Passenger Aviation and High-Speed Rail: A Comparison of Emissions Profiles on Selected European Routes*" (Prussi M., 2018), *"Airline and high-speed rail competition in Europe: Towards a comeback of air transport?"* (Dobruszkes, 2010), and "*Air Transport versus High-Speed Rail: An Overview and Research Agenda*" (Sun X., 2017).

Data concerning the current aviation situation were reviewed from the report *"Aviation tracking Clean Energy Progress IEA"* (Scheffer, 2019).

2. Background: European policies in the transport sector

Nowadays, the total European GHG emissions are a matter of concern for the EC, the reason why several measures and initiatives stepped-in in the EU context.

In this context, the Commission has put together a package of binding targets and the most crucial transport energy policies like the 2050 Energy Roadmap, the White Paper on Transport, and the Green paper on urban transport as a fundament for identifying sector-specific policy initiatives.

The EC on Member States starts to launch a range of action plans for developing new infrastructure for clean fuels such as electricity, hydrogen and natural gas, as well as common EU-wide standards for the equipment needed, to promote the use of alternative fuels as reinforcement of the unified European market *(EC, Alternative fuels for sustainable mobility in Europe, 2019*).

The following inter-institutional negotiations are documented in the final Directive that was adopted by the European Parliament and the Council on 29 September 2014 (*EC, 2014*).

- It requires Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure;
- It foresees the use of standard technical specifications for recharging and refueling stations;
- It paves the way for setting up proper consumer information on alternative fuels, encompassing a clear and price scheme comparison methodology (*EC, Towards the broadest use of alternative fuels - an Action Plan on Alternative Fuels, 2017*).

2.1 Total European greenhouse gas emissions

As reported in the EEA's Annual EU GHG inventory 1990-2017 report (EEA, 2019), the EU's GHG emissions declined steadily between 2010 and 2014. After that, the trend started to grow again until 2017, showing an increase of 0.7% compared to the previous year.

In 2017, the total GHG emissions in EU Countries decreased by 22 % compared to 1990 figures (Fig.1), leading to an overall reduction of 1 240 million tonnes (Mt) of CO2eq. This sets the EU on track to meet its 2020 target, which foresees a reduction in GHG emissions by 20 % by 2020 and by 40 % by 2030 compared to 1990

(Eurostat, How are emissions of greenhouse gases by the EU evolving?, 2019).

In 2017, the share recorded in the overall GHG emissions per sector was split as follows: 28.2 % was coming from the energy-producing industries; 25.8% by fuel combustion by users, followed by the transport sector with 24.6 %.

If the percentage of the overall GHG emissions per sector decreased substantially over the considered timeframe, the transport sector made an exception, reporting an increase in emissions of about 9,5% from 1990 to 2017.

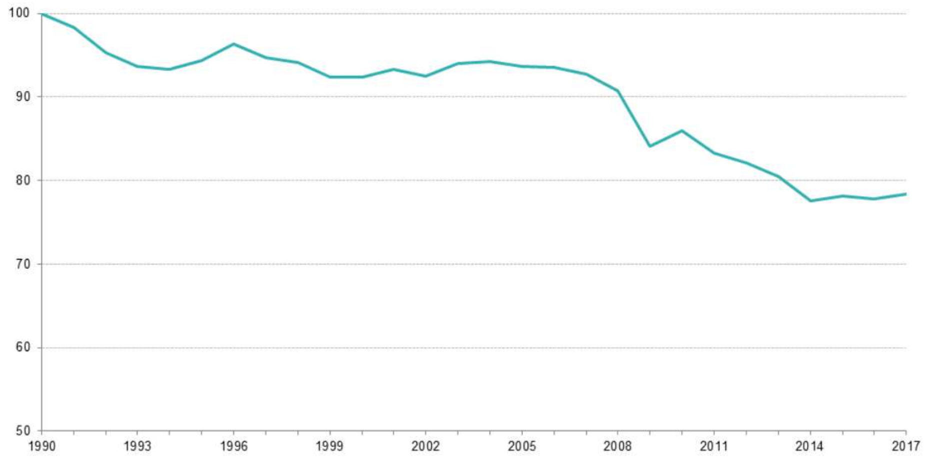

Figure 1: Total greenhouse gas emissions EU-28, 1990-2017 historical development, 1990–2017(Index 1990 = 100%)

*Source: **(Eurostat, Greenhouse gas emission statistics - emission inventories, 2019)***

The most substantial emission cuts have been reported in the energy sector due to efficiency improvements, increased use of renewables, and less carbon-intensive fossil fuels.

Energy efficiency and renewable energy will continue to play a crucial role in cutting future emissions and helping the EU achieve its 40 % reduction target by 2030.

2.2 Current EU transport GHG´s emission data

In 2017, the transport sector mainly drove the 0.7 % increase in EU GHG emissions. As is shown in Fig. 2, the GHG emission related to the transport sector was steadily increasing from 1990 until 2007 (+31%), reaching the highest level of CO2 emissions. The historical trend shows then a drop (-12%) from 2008 to 2013, and afterward, an exponentially increase until 2017. GHG from the transport sector (including all international aviation but excluding GHG emissions completely of the international shipping) have still been higher in 2017 than 26 % compared to 1990 levels.

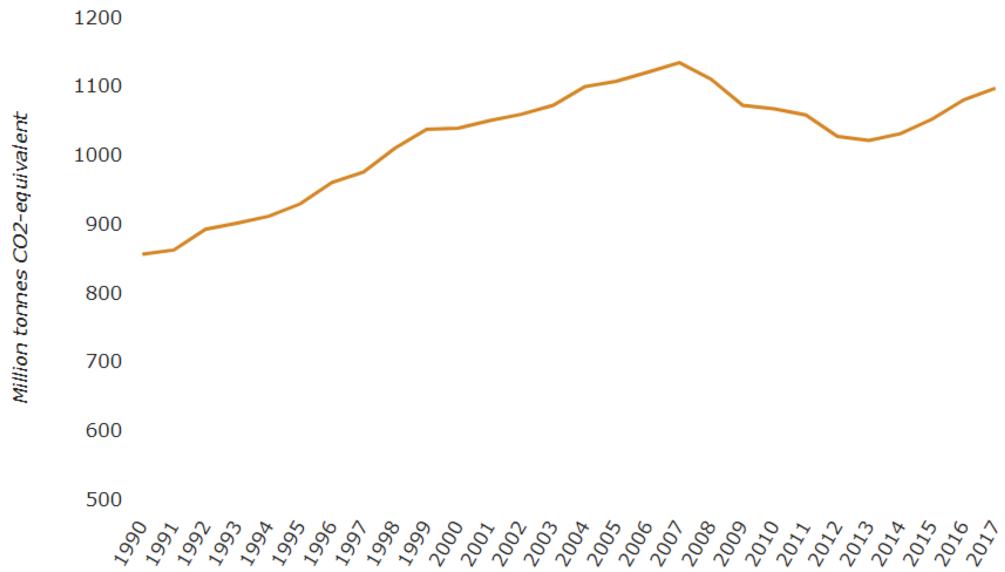

Figure 2: Greenhouse emission from transport, EU
*Source: **(EEA, 2018)***
Note: National emissions reported to the UNFCCC and the EU Greenhouse Gas Monitoring Mechanism

European Environment Agency published a comparison between the years 1990 and 2017 concerning the European GHG emission by the aggregated sector (Fig.3). The figure shows the transport has not seen the same gradual decline in emissions as the other sectors, on the contrary, from 1990 to 2017 there was a percentage increase of 10 %.

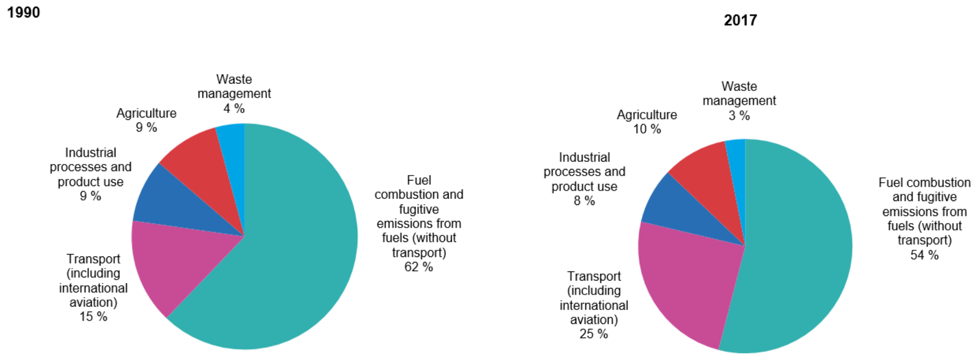

Figure 3: Greenhouse Gas emission (GHG) in the EU by the aggregated sector. Data comparison 1990-2017
Source: ***EEA*** *(Eurostat, Greenhouse gas emission statistics - emission inventories, 2019)*

In comparison with 2015, emissions in 2016 have been risen by almost 3 %, according to EEA, where the bigger share in emission is counted by the road transport area, followed by aviation.

In 2016, transportation (including aviation and shipping) contributed 22 % of total greenhouse gas emissions in the EU-28.

In the whole transport sector, road transport is by far the biggest emitter accounting for 72% of all GHG emissions from transport in 2016, according to the data provided by the EEA (Fig.4)

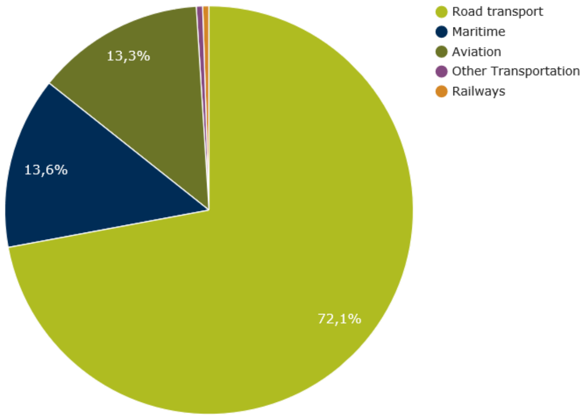

Figure 4: Share Greenhouse Gas Emission by mode of transport in EU Countries 2016
*Source: **(EEA, 2018)***

According to EEA 2018, CO2 emissions from road transport in Europe are split as follows: passenger cars are a major polluter, accounting 61% of the total road transport CO2 emission, 26% is coming from heavy-duty trucks, 12% from light-duty vehicles and 1% from motorcycles.

Diesel represents the major contributor in releasing CO2 emission, followed by petrol vehicles. European Commission introduced in 2003 the use of biodiesel through a Biodiesel directive and a series of standard limit emission starting from 1992, with the purpose to reduce the GHG emissions of diesel and petrol vehicles. The latest standard is Euro VI, which aims to further reduce NOx emission from diesel engines (67% reduction compared to Euro V).

The increasing quantity of Fatty Acid Methyl Ester (FAME) in the diesel blending and the introduction of hydro-threated vegetable oil (HVO) in the internal combustion diesel engines (ICDEs) could generate a further reduction in CO2 emission coming from passenger cars and heavy and light vehicles.

The aviation sector represents another alarming source in terms of emissions generation, and it is the fastest-growing source of GHG emissions in the whole transport sector, as a result of higher demand and consumption of jet kerosene. Of the overall European GHG emissions, 3% is directly coming from aviation account, and more than 2% contribute to the global emissions (EC, Reducing emissions from aviation, 2019). The environmental impact of planes is complicated and not entirely understood.

Plane engines generate not only CO_2 emissions but also other "outputs," including nitrous oxide, water vapor, and soot, that are a cause of climatic effects and impact on the environment.

The nitrous oxide is the major source for the formation of ozone, and other GHG's that warm the local climate, the soot, and water vapor can cause contrails (vapor trails), and together with cold air can lead to the formation of cirrus clouds.

The experts consider the total environmental impact from the aviation sector as the double rate of CO_2 emissions, where the determining factors are: the type of aircraft, the climatic conditions, the duration of the flight, and the time of the day (morning or evening).

It has been scientifically proven that flying in and back from London to New York generates approximately the same level of emissions as the average person in the EU does by heating their home for a whole year.

The CO_2 emissions of all flights departing from EU28 has risen from 88 to 171 million tonnes (Mt) (+95%) from 1990 to 2016 (*EASA, 2019*), according to the data released by the Members States to the United Nations Framework Convention on Climate Change (UNFCCC), (Fig.5).

The CO_2 emissions estimated with the "IMPACT model" reached 163Mt in 2017, which is 16% more than in 2005 and 10% more than in 2014.

The average fuel burn by the aircraft per passenger-kilometer (pkm), excluding business aviation, went down by 24%, an achievement that reduced at an average rate of 2.8% per annum between 2014 and 2017. However, this increase in efficiency was not high enough to even out the rise in CO_2 emitted because of the growth in the number of flights, aircraft size, and the distance covered. It is expected that the future CO_2 emissions in the base-case traffic forecast and advanced technology scenario will increase by an additional 21%, reaching the 198 Mt in 2040. The annual purchase of allowances by aircraft operators under the EU Emissions Trading System (ETS) since 2013 resulted in a reduction of 27 Mt of net CO_2 emissions in 2017, which should increase to about 32 Mt by 2020.

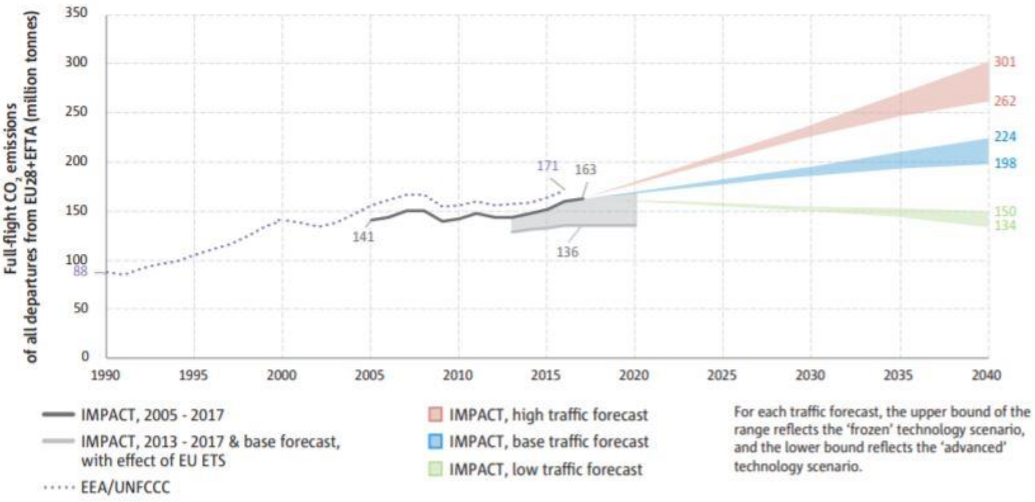

Figure 5: Historical and forecast development in MioTons of CO2 emission by the aviation sector 1990-2050

Source: **(EASA, 2019)**

2.3 European policies and future strategies in the transport sector

After the Kyoto Protocol, the first international agreement aimed to reduce GHG emissions on a global scale, EC decide to develop and implement its climate-related initiatives. In fact, in June 2000, the EU launched the ECCP *(EC, European Climate Change Programme, 2019*) to avoid the increase of GHG emissions, identify and develop all the necessary measures of an EU strategy to implement the Kyoto Protocol Commitments. Many EU Climate Action followed the ECCP as 2020 Climate and energy package, 2030 climate and energy framework, and the 2050 long-term strategy.

Only fifteen years after the Kyoto Protocol, the EU starts focusing on key transport policy issues, taking then the decision to develop effective action plans such as Green paper on urban transport (*EC, 2007*), EU clean fuel strategy (*EC, 2013*), and White paper (*EC, 2011*).

In the timeline in Fig.6, the main initiatives and directives proposed over the last ten years by the EC are documented.

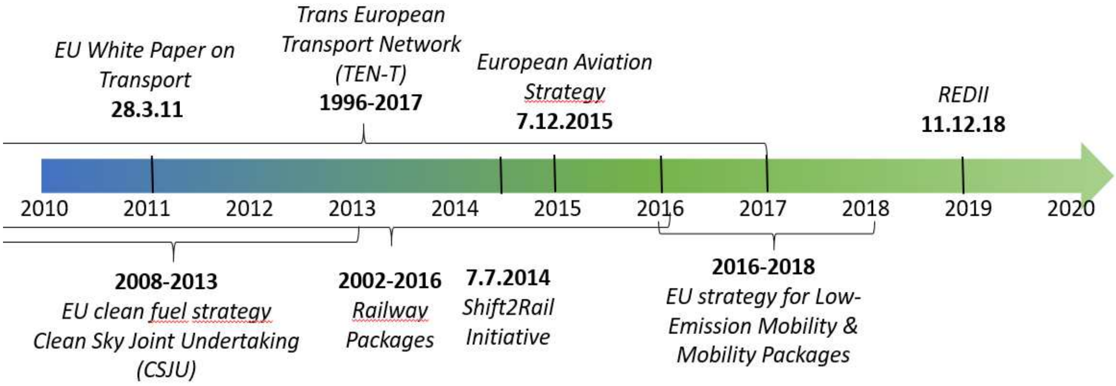

Figure 6: Representative timetable of the primary directives and policies committed by the European Commission in the last decades - Own Figure

2.3.1 The EU white paper on transport

In March 2011, the EC adopted a White paper titled "Roadmap to a single European transport area" — towards a competitive and resource-efficient transport system *(EC, 2011*).

In the EU Transport White Paper, where settled short-term and long-term targets for transport emissions:

- 20% reduction from 2008 levels by 2030,
- 60% reduction from 1990 levels by 2050.

The White Paper sets a series of measures and environmental goals to be achieved by 2050, to further decarbonize transport in Europe, including:

- excluding conventionally-fuelled cars in cities;
- accomplishing a 50 % shift in medium-distance inter-city passenger and freight journeys from road to either rail or waterborne transport;
- progressing towards zero traffic fatalities;
- increasing to 40 % the use of sustainable low-carbon fuels in the aviation sector;
- reducing shipping emissions by at least 40 %;
- completing the European high-speed rail network.

The main challenge for the transport sector in the EU is represented by creating a well-functioning Single European Transport System. The EU decided to invest in the TEN-T project, connecting Europe with new, multi-modal, and safe transport infrastructure connections to reduce emissions.

2.3.2 The Trans-European Network (TEN-T)

The increase in air traffic and emissions led the launch of a new ambitious EU-program so-called TEN-T that sees the development of new infrastructure, through a modern integrated transport system, with the scope to ensure a well-functioning network that can transport people and goods efficiently, safely and sustainably.

The Trans European Transport Network program plays a crucial role in the Europe 2020 strategy for smart, sustainable, and inclusive growth *(EC, TEN-T Projects, 2019*).

With a focus on economic development, the main objectives of this plan are increasing regional competitiveness, regional and social cohesion, and environmental sustainability, optimizing the interconnection and interoperability of national transport networks, integration, and interconnection of all transport modes, and the efficient use of infrastructure.

The TEN-T is a system consisting of a set of infrastructures, fixed installations, logistic equipment, and rolling stock. It plans and includes the construction of over 217 000 km of railways, 77 000 km of motorways, 42 000 km of inland waterways, 329 principal seaports, and 329 airports *(EC, Infrastructure and Investment | Mobility and Transport, 2019*).

Furthermore, the TEN-T project includes an important sub-program in the railway sector, the Trans-European Rail- Network, which, in turn, is subdivided into the Trans-European high-speed rail network *(EC, Council Directive 96/48/EC of 23 July 1996, 2012*) and Trans-European conventional rail network *(EC, Directive 2001/16/EC, 2001).*

On 17 October 2013, the EU announced the planning of nine "core network corridors" within the TEN-T framework (Fig.7) which are:

- The Baltic-Adriatic Corridor (Poland–Slovakia–Austria–Italy)
- The North Sea-Baltic Corridor (Finland–Estonia–Latvia–Lithuania–Poland–Germany–Netherlands/Belgium)
- The Mediterranean Corridor (Spain–France–Northern Italy–Slovenia–

Croatia–Hungary)

- The Orient/East-Med Corridor (Germany–Czech Republic–Hungary–Romania–Bulgaria–Greece–Cyprus)
- The Scandinavian-Mediterranean Corridor (Finland–Sweden–Denmark–Germany–Austria–Italy)
- The Rhine-Alpine Corridor (Netherlands/Belgium–Germany–Switzerland–Italy)
- The Atlantic Corridor (Portugal–Spain–France)
- The North Sea-Mediterranean Corridor (Ireland–UK–Netherlands–Belgium–Luxembourg–south of France, because of Brexit changed to Ireland–Belgium Netherlands and Ireland–France)
- The Rhine-Danube Corridor (Germany–Austria–Slovakia–Hungary–Romania, waterway focus) (*EC, Inea conencting europe facility - INNOVATION AND NETWORKS EXECUTIVE AGENCY, 2019*)

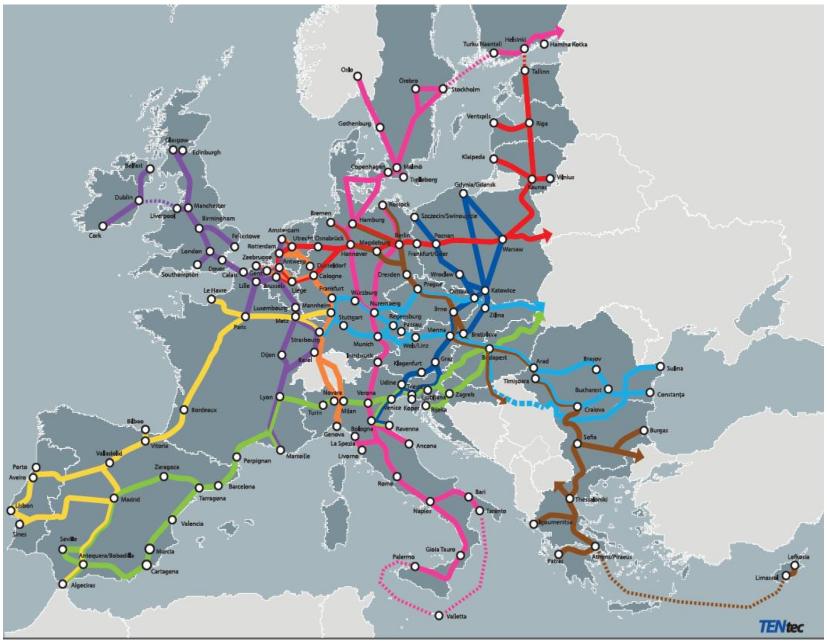

Figure 7: Trans-European Transport Network.
Source: ***(UN, 2017)***

2.3.3 The Shift2 train initiative

In recent years, the European Commission put in place many efforts to develop valid solutions to increase the rail sector competitiveness.

The "first Railway Package" was implemented by the EU in 2001, followed by the commissioning of the White Paper on Transport in 2011. Both papers represented a step forward into the railway sector in which the EC clearly claimed its willingness to support rail revitalization.

From 2002 until 2016, the second, third, and fourth Railway Packages have followed. The most recent, the 4th Railway Package, consists of a series of six legislative regulations designed to complete the single market for rail services (Single European Railway Area) and establishing the European Union Agency for Railways *(EC, Regulation EU 2016/796, 2016)*.

The package comprises two ‘pillars’:

- 'technical pillar,' focused on the interoperability of the rail system within the EU and rail safety, each adopted in April 2016 *(Directive EU 2016/798, 2016*);
- 'market pillar,' to complete the gradual market opening and the award of public service contracts for domestic passenger transport services by rail *(EC, Regulation EU 2016/2338, 2016*), the governance of railway infrastructure *(Directive EU 2016/2370, 2016*), and the normalization of the accounts of railway *(Regulation EU 2016/2337, 2016*) undertakings, each adopted in December 2016.

Today, the total EU-28 railway length is about 230,000 km, but significant differences are present across the EU area, especially in terms of railway speed connection.

The conventional rail network is split into the following categories:

- lines intended for passenger services
- lines intended for mixed traffic (passengers and freight)
- lines specially designed or upgraded for freight services
- passenger hubs
- freight hubs, including intermodal terminals

The infrastructure network includes traffic management, tracking, and navigation systems.

The Shift2Rail focuses on R&I and market-driven solutions for promoting the competitiveness of the European rail industry (*S2R-a, 2018*).

In this framework, Shif2Rail seeks the challenging targets to double the capacity of the European rail system, increasing reliability and service quality by 50%, while increasing lifecycle performance.

The project is carried out under the "Horizon 2020", initiative that supports the completion of the Single European Railway Area (SERA). The implementation of a new rail network in the EU also includes the development of high-speed rail (HSR) projects.

High-speed lines are part of the rail network of Belgium, Germany, Spain, France, Italy, the United Kingdom, the Netherlands, Austria, and Poland.

From 2010 and 2016, the high-speed network expanded by 1,400 km (31%), and by 2030, the planned high-speed Trans-European Transport Network should extend HSR to over 30,000 Km (*EC, Rail Report 2016, 2017*).

The availability of High-Speed Train (HST) lines opens the possibility of partial substitution with short-haul and medium-haul intra-EU flights.

2.3.4 The European aviation strategy

In December 2015, the EC adopted an "*Aviation Strategy for Europe"* (*EC, 2015*) to develop a more competitive business area with more benefits for a rapidly evolving and expanding global economy.

The top priorities of this strategy were stepping into growth markets by investing and improving services, efficiency, and connectivity and maintaining high EU safety and security standards.

The Single European Sky packages are an European Commission initiative that seeks to reform the European air traffic management system through a series of actions carried out in four different levels (institutional, operational, technological and control and supervision). The aim is to satisfy the needs of the European airspace in terms of capacity, safety, efficiency and environmental impact *(EC, Single European Sky II, 2009*).

In regards to the environmental impact, in the timeframe 2008-2013, it developed one of the most significant European research projects ever, with a budget estimated at €1.6 billion, equally shared between the European Commission and the aeronautic industry so-called "Clean Sky Joint Undertaking (CSJU)."

The aim of this initiative is to coordinates and provides the necessary funding to develop and introduce innovative technologies into the aviation sector. The CSJU is intended to be the main contributor in realizing "*the Advisory Council for Aeronautics Research in Europe (ACARE) 2020 environmental goals for the industry*" *(EC, CLEAN SKY 2, 2019).*

Different goals have been set to mitigate the environmental impact of the lifecycle aircraft and related products to reduce:

- 50% in carbon dioxide (CO2) emissions,
- 80% in mono-nitrogen oxides (NOx) emissions,
- 50% in noise for flying aircraft.

In October 2016, the International Civil Aviation Organization (ICAO) agreed on a resolution for a global market-based measure to address CO2 emissions from international aviation as of 2021 (EC, Reducing emissions from aviation, 2019). All developments and environmental performance of the EU's air transport sector are reported on the "European Aviation Environmental Report."

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), aims to offset around 80% of the emissions above 2020 levels and stabilize CO2 emissions at 2020 levels by requiring airlines to offset the growth of their emissions after 2020 (*AWG, 2019*). During the period 2021-2035, airlines will be enforced to monitor the emissions from all international routes, and to offset emissions provided by the routes included in the scheme by purchasing eligible emission units from energy-saving projects in other sectors (e.g., renewable energy).

2.3.5 The EU's legislation on road transport

Further legislation to cut and bring down CO2 emissions from new road means of transport has recently been implemented by EC.

A 40% decrease in emissions from new vehicles in 2021 compared to 2005 and a 19% decrease for new vans in 2020 compared to 2012. These targets and goals will directly translate into increased energy efficiency and the sustainability and competitiveness of new vehicles. More tight standards will also encourage and challenge the introduction of alternative powertrains, such as hybrid (HVs) and compressed natural gas (CNG) and electric vehicles (EVs).

The climate and energy proposals for 2030 aim not only to intensify the EU's strategy to reduce CO2 emissions from vehicles but also to reduce the GHG concentration of fuels by 6% by 2020. Public authorities are required to take into account lifetime energy consumption and CO2 emissions when purchasing vehicles.

Low-emission Mobility Strategy & Mobility Packages

The Commission seeks to address the shortcomings in the integration of the road transport market through a series of initiatives for a socially just transition to clean, competitive, and related mobility. These principles are presented in the 2016 Low Emission Mobility Strategy, followed by three waves of legislative proposals, the so-called "mobility packages." (*EC, COM(2016)501, 2016*)

The European Strategy for Low-Emission Mobility highlights the focus areas:

- digital mobility solutions;
- fair and efficient pricing in transport (which should reflect the negative externalities of transportation);
- promotion of multi-modality;

- framework for alternative energy;
- roll-out of infrastructure for alternative fuels;
- interoperability and standardization for electro-mobility;
- improvements in vehicle testing;
- post-2020 research and investment strategy for all means of road transport.

The strategy includes a broad set of measures to support Europe in its transition into a green and sustainable economy, supporting jobs, growth, investment, and innovation. The strategy will benefit European citizens and consumers by delivering improvements in air quality, lower congestion levels, and improved safety. Consumers will benefit from less-energy consuming cars, better infrastructure, alternative fuels, and fewer delays thanks to the roll-out of digital technologies. The policy identifies three priority areas for action:

1. increase the efficiency of the transport system through technological digitization, smart and competitive prices and by further encouraging the shift to low-emission modes of transport;
2. accelerate the development of low-emission alternative energies for transportation, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels, and remove obstacles to transport electrification;
3. Shift to zero-emission vehicles: further improvements to the internal combustion engine will be needed, Europe needs to accelerate the transition to low- and zero-emission vehicles.

These measures will make the EU transport system more efficient and integrated, accelerating the introduction of new vehicle and fuel technologies through CO2 standards. The goal is also to encourage the shift to cleaner and more competitive means of transport such as rail, improving traffic management through the use of intelligent transport systems, and removing obstacles to the broader deployment of alternative powertrains such as electric vehicles through the Clean Power for Transport initiative and the Clean Power for Transport and Clean Fuel strategy.

Clean fuel strategy & clean power for transport package

Transport in Europe is hugely dependent on oil (circa 94%), and alternative fuels are urgently needed to break the European transport sector's dependence on fossil fuels.

Research and technological development have shown that alternative fuel solutions could be implemented for all modes of transport, but clean fuel has three main constraints: the high price of vehicles, a low level of market penetration, and the lack of charging and refueling stations. Unfortunately, this is a recurring issue: the filling stations are still low because there are not enough vehicles, the vehicles are not sold at competitive prices because there is not enough demand, consumers do not buy vehicles because they are expensive reason why there are not enough stations.

To solve this problem, the EC suggests a package of binding targets for Member States for a minimum level of infrastructure for clean fuels like electricity, hydrogen and natural gas, as well as common EU broad standards for equipment needed, with the aim to promote the development of a single market for clean and renewable fuels for transport in Europe (*LNG World News, 2019*). In this context took over the Clean Fuel and Power for Transport Package which launched a European alternative fuels strategy. The final Directive [1] The European Parliament and the Council adopted on 29 September 2014, a directive which describes an action plan for the development of different measures that need be considered in the transport sector in each technology or energy carrier as:

- Electricity: the electric charging points vary significantly across the EU. Germany, the Netherlands, France, Spain, and the UK are the leading EU countries. Under this proposal, a minimum number of recharging points, desponding of a conventional European plug[2]. The core target of this proposal is to deploy a critical

[1] Directive 2014/94/EU requires Member States to notify to the European Commission National Policy Frameworks (NPFs) for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure.
[2] A standard EU wide plug, is an essential element for the roll-out of this fuel. Commission has announced the use of the "Type 2" plug as the conventional standard for the whole of Europe.

mass of electricity charging points with the scope to enables companies to introduce mass production of the cars at decreasing prices.

- Hydrogen: existing filling stations will be linked up to form a network with common standards, ensuring the mobility of Hydrogen vehicles. It applies to the 14 Member States, which currently has a Hydrogen network.
- Biofuels: the share of 2018 biofuel imports to the EU-28 doubled compared to 2017. An advantage of this energy carrier is that they work as blended fuels and do not require any specific infrastructure. A key challenge will be to ensure its sustainability.
- Natural Gas, Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG): LNG is used for waterborne transport at sea and on inland waterways, but the infrastructure for fuelling vessels is at a very early stage. Concerning the LNG used for the road transport sector, it is mainly thought for truck fuelling, but only 38 filling stations are currently available in Europe. The Commission is proposing to install refueling stations every 400 km along the roads of the Trans European Core Network by 2020.
- CNG: Compressed natural gas is mainly adopted for cars. Currently, about one million vehicles use CNG representing 0.5% of the fleet. The industries aim to enhance this figure ten-up to the year 2020. The proposal of the EC will ensure that publically accessible refueling points, with common standards, are available Europe-wide with maximum distances of 150 Km by 2020 *(Journal, 2013*).

It is expected that Member States can implement these new regulations without significant new public expenditure by only replacing the current local regulations with new ones to encourage private sector investment and individual decisions.

EU support is already available through the TEN-T, Cohesion and Structural Funds.

The directive "*Alternative fuels for sustainable mobility in Europe*" requires Member States (*EC, 2019*):

- to develop national policy frameworks for the market development of alternative fuels and their infrastructure;
- foresees the use of standard technical specifications for recharging and refueling stations;
- paves the way for setting up appropriate consumer information on alternative fuels, including a transparent price comparison methodology.

The EC is today taking action to modernize European mobility and transport; it proposed a wide range of implementing measures:

- environmental commitments — such as those under the Kyoto Protocol, as well as air quality, noise pollution, and land use;
- development in new technologies — this included the encouragement of further research and development into areas such as intelligent transport systems involving communication, navigation and automation, engine technology that could improve fuel efficiency, and the promotion of alternative fuels.

Such as Galileo, the European Global Navigation Satellite System (GNSS), provides better positioning and timing information, with positive implications for many European services and users.

Galileo services make Europe's roads and railways safer and more efficient.

In this context, the exploitation of Galileo and its integration with other sensors is crucial for developing accurate solutions for current and future smart urban planning. In this direction, the GHOST *(EC, Galileo Enhancement as Booster of the Smart Cities, 2019)* project funded by Horizon 2020 is developing and validating an intelligent system for existing public transport fleets with a Galileo-enabled camera and links these vehicles to a web portal.

Another example is SESAR (*EC, 2014*), with the scope to digitalize the European aviation infrastructure and ERTMS, European Rail Traffic Management System *(EC, 2017*). The main target of this tool is to enhance cross-border interoperability of rail transport in Europe, increasing the efficiency of train transports by replacing former national signaling equipment and operational procedures with a single new Europe-wide standard for train control and command systems.

Digitization and use of these intelligent systems is an essential step in this transport transition, which will also need to be followed by investments in new technologies the combination of these two factors will define the radical shift to renewable energies in designing and developing the smart cities of the future.

2020 EU Renewable Energy Directive (RED II)

In 2016, the EC presented an updated version of the Renewable Energy Directive so-called RED II for the timeframe 2021 – 2030, as a part of "Clean Energy for all Europeans package," (*EC, RED II Directive, 2018*).

It entered into force in December 2018, aimed at contributing the EU to meet its emissions reduction commitments under the Paris Agreement.

The RED II defines sustainably criteria for liquid biofuels used in transport, as well as for biomass fuels, power, heating, and cooling products.

The new directive sets a new binding EU renewable energy target for 2030 of at least 32%, with a clause for a possible upward revision by 2023. Member States must require fuel suppliers to supply at least 14% of the energy consumed in road and rail transport as renewable energy by 2030.

Directive 2009/28/EC specifies national renewable energy targets for 2020 for each European country, taking into account the starting point and overall potential of renewable energy. These targets range from a minimum of 10% in Malta to a maximum of 49% in Sweden.

EU countries have set out how they intend to meet the targets settled for 2020 and the overall direction of their renewable energy policies in their National Renewable Energy Action Plans. Member States are required to submit their Final National Energy and Climate Action Plans (NECPs) to the EC by the end of 2019, and, besides, progress towards the national targets is measured every two years when EU countries publish national progress reports on renewable energy.

Most of the other new elements in the new directive need to be commuted into national policies by the Member States by 30 June 2021.

While the whole EU is on track to meet its 2020 targets, some European Countries will need to make additional efforts to meet their obligations as regards the specific share of energy from renewable sources in transport in the gross final energy consumption

(Fig. 8). However, [3]The European renewables consumption in this sector reported a steady growth (Fig.9), as a result of the restrictive European blending regulations.

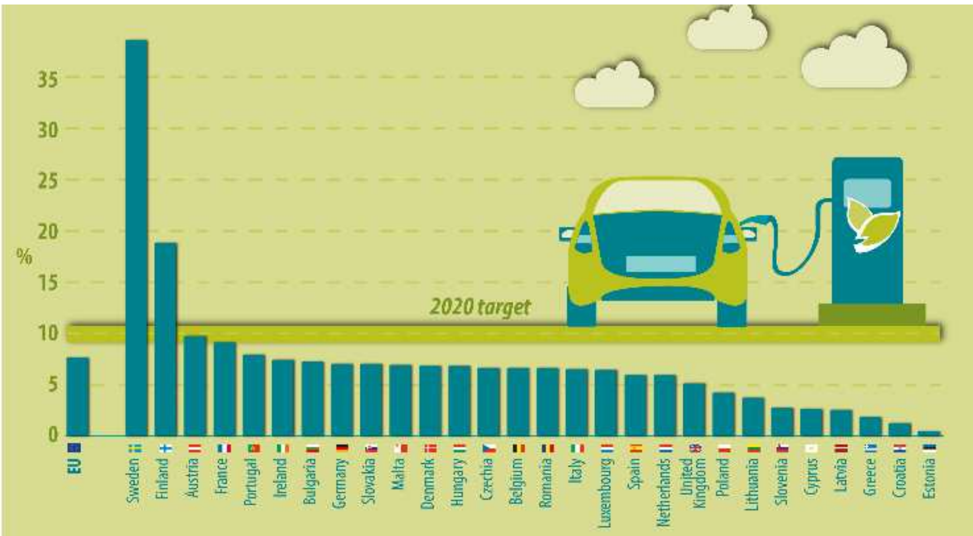

Figure 8: Share of energy from renewable sources in transport (2017, in % of gross final energy consumption)
Source: Eurostat (2018)

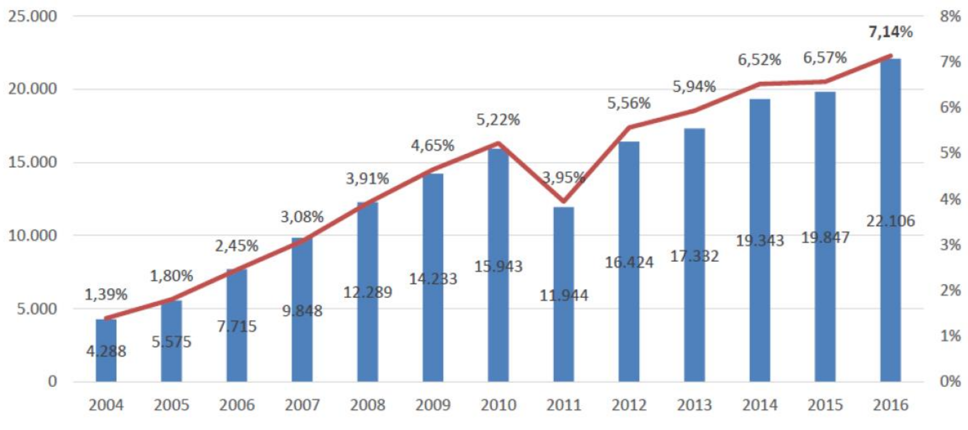

Figure 9: Evolution of renewable energy consumption in the transport sector in the EU (ktoe and %)
Source: ***Bioenergy Europe 2018 report – Eurostat, SHARE 2016***

[3]2011 was signed by a decline in investment resulted from uncertainty over support policies in Europe, as well as from actual retroactive reductions in support.

3. Development of the public transport sector in the EU

According to the latest Statistical Pocketbook 2018, the passenger's transport trend increased over the past 20 years (*Eurostat, Statistical Pocket, 2018*). However, the exponential growth of the goods in transport reported a break down in 2009, caused by the economic crisis, and resumed from 2010 on. Indeed the Gross Domestic Product (GDP[4]) shown two peaks, one in 2009 and another in 2012, and it grew afterward, exceeding the levels reached before the pre-crisis level. (Fig.10).

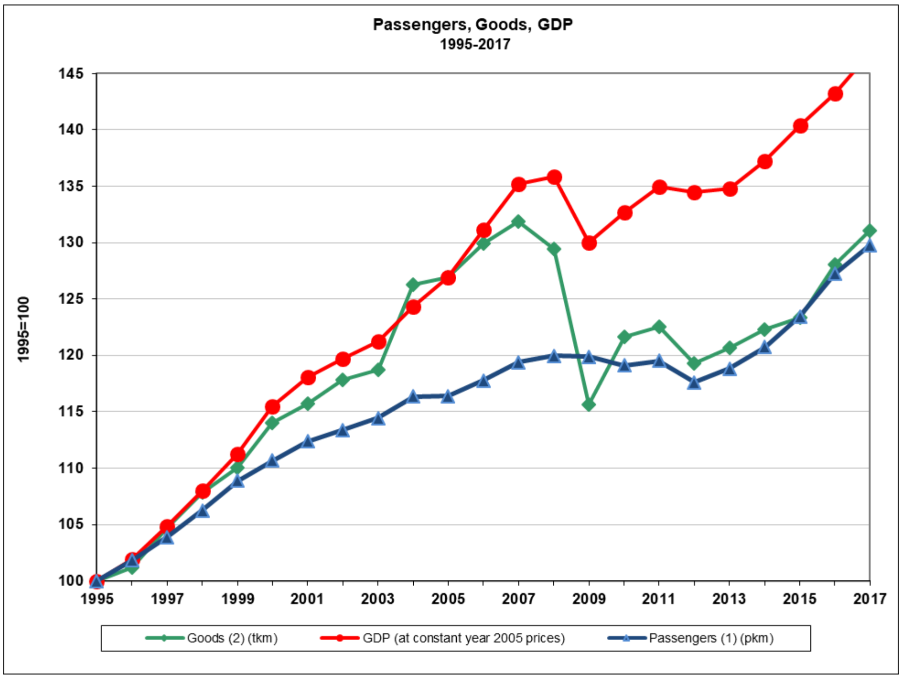

Figure 10: Transport Growth EU-28 1995-2017
Source: ***(Eurostat, Statistical Pocket, 2018)***

[4] GDP: Gross Domestic Product. It is a monetary measure of the market value of all the final goods and services produced

Notes:

(1): passenger cars, powered two-wheelers, buses & coaches, tram & metro, railways, intra-EU air, intra-EU sea

(2): road, rail, inland waterways, oil pipelines, intra-EU air, intra-EU sea

GDP: at constant year 2005 prices and exchange rates

The historical trend concerning passenger growth in EU transport from 1995 to 2017 shows, on average, an increasing trend except for the years 2009 and 2012.

The amount of the total passengers counted in the EU-28 in 2016, for Bus & Coaches, Railway, and Aviation reached about 1 715 billion pkm or on average, around 13 314 km per person (Tab.1).

Table 1: Passenger Transport per means of transport Statistical Data 1995-2016. Data Source: ***(Eurostat, Statistical Pocket, 2018)*** *- Own table*

PASSENGER PER TRANSPORT
(billion pkm)

Year	Bus & Coach	Railway	Air	Total
1995	515	350	348	1 213
2000	551	372	460	1 383
2005	549	378	530	1 457
2006	546	390	552	1 488
2007	559	397	575	1 531
2008	570	413	563	1 546
2009	548	405	524	1 477
2010	544	407	535	1 486
2011	548	416	577	1 541
2012	546	421	570	1 537
2013	544	427	580	1 551
2014	540	434	610	1 584
2015	550	443	640	1 633
2016	552	450	713	1 715
CAGR 2016 vs 1995%	*0,3%*	*1,2%*	*3,5%*	*1,7%*
2016 vs 1995 %	*7%*	*29%*	*105%*	*41%*
2016 vs 2000 %	*0%*	*21%*	*55%*	*24%*

As showed in the table above, all three means of transport grew over the last 20 years, reporting a compound annual growth (CAGR) 2016 vs. 1995 of +1,7 %: Air transport and Railway grew +3,5% and +1,2% respectively, while Bus & Coaches only +0,3%. If we compare the passenger performance of 2016 vs. 1995, Air reported an extraordinary growth of +105%; Railway grew double-digit with +29% and Bus & Coaches +7%.

We need to go back to the year 1992 to understand the exceptional air traffic growth better. Since the EU's Internal Market for Aviation was born in 1992, there has been a revolution in air travel. Today, air travel is cheaper, safer, and more accessible, thanks to EU initiatives that replace a set of national rules by a single set of EU legislation, known as the Single European Sky Package I and II.

On the other hand, the Commission is also fully involved in the revitalization and modernization of the rail sector in order to provide citizens with a high-quality rail transport service throughout the EU. The main objectives are to improve rail infrastructure management, to promote the development of new technologies to build a modern and competitive rail network and to make rail transport a privileged tool for European integration.

This achievement led to a substantial growth of train passengers over the last twenty years.

Looking at the modal Split of passenger per means of transport (Tab.2), Air share reached 41,6% in 2016, growing +13 percentage point (ppt) versus the 28,7% recorded in 1995, while Bus & Coaches lost -10 ppt over the last twenty years. Railway was the only mean of transport that remained stable, however losing circa 3 ppt (2016 vs. 1995).

Table 2: Modal split per means of transport Statistical Data 1995-2016 (% share in tons-kilometer).
*Source: **Statistical Pocketbook EU Transport (2018)** – Own table*

MODAL SPLIT

Year	Bus & Coach	Railway	Air
1995	42,5%	28,9%	28,7%
2000	39,8%	26,9%	33,3%
2005	37,7%	25,9%	36,4%
2006	36,7%	26,2%	37,1%
2007	36,5%	25,9%	37,6%
2008	36,9%	26,7%	36,4%
2009	37,1%	27,4%	35,5%
2010	36,6%	27,4%	36,0%
2011	35,6%	27,0%	37,4%
2012	35,5%	27,4%	37,1%
2013	35,1%	27,5%	37,4%
2014	34,1%	27,4%	38,5%
2015	33,7%	27,1%	39,2%
2016	32,2%	26,2%	41,6%

Comparing the three means of transport (Fig. 11), we could observe a positive trend in Air and Railway sector, which probably will continue in the next years.

This growth will be led by two main factors: the high investment in high-speed trains and the increase in passenger demand, with a consequent decrease in airfares.

Bus & coaches have remained stable during the last years; however, the potential is still high since passengers still prefer a car in small-medium cities.

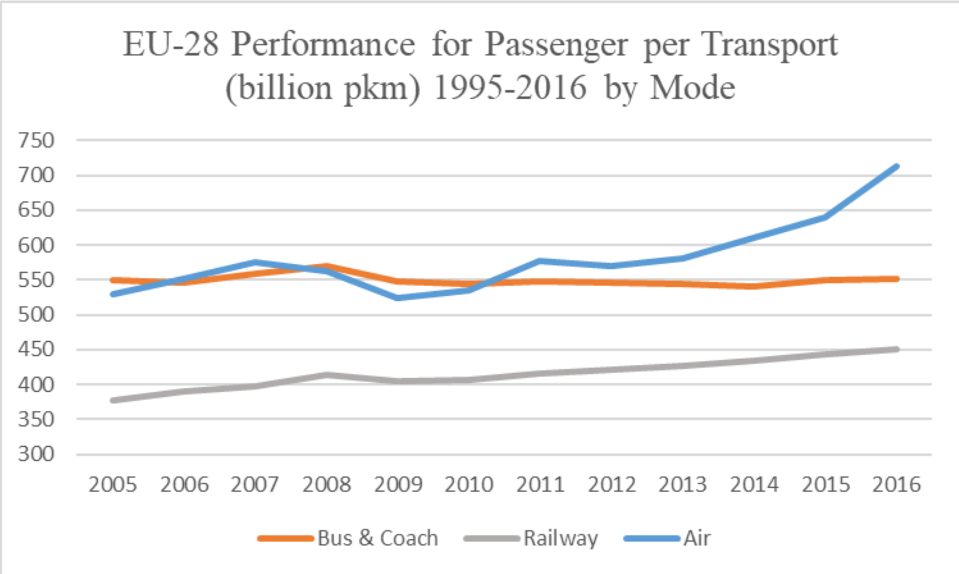

Figure 11: Trend of Passenger Transport per means of transport Statistical Data 1995-2016
Source: ***Statistical Pocketbook EU Transport (2018)*** *– Own Figure*

3.1 The sector of air passenger transport -statistical data

As it is shown in the graphic below (Fig.12), almost the 47% of the air passenger transport concerned intra-EU flights, while national transport and extra-EU transport accounted for 17% and 36% (*Eurostat, Air transport statistics, 2019*)

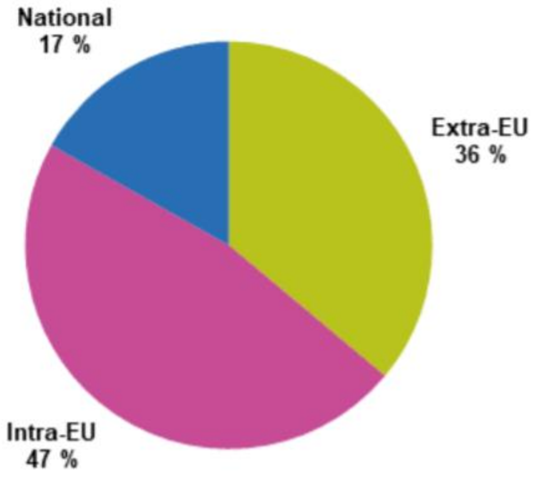

Figure 12: Overview of EU-28 air passenger transport in 2017
Source: ***Eurostat (2017)***

Between 2016 and 2017, the average growth of air passengers in the EU-28 was 7.25%.

The data revealed disparities at the national level, with annual increases ranging from 1.5% in Denmark to +19.8% in Slovenia. (Fig.13).

All EU-Countries showed an increase in 2017 in term of passengers: the most prominent countries (Germany, Italy, France, UK, and Spain) reported a growth between 6% and 8%, while many small countries reported grew more than 10%

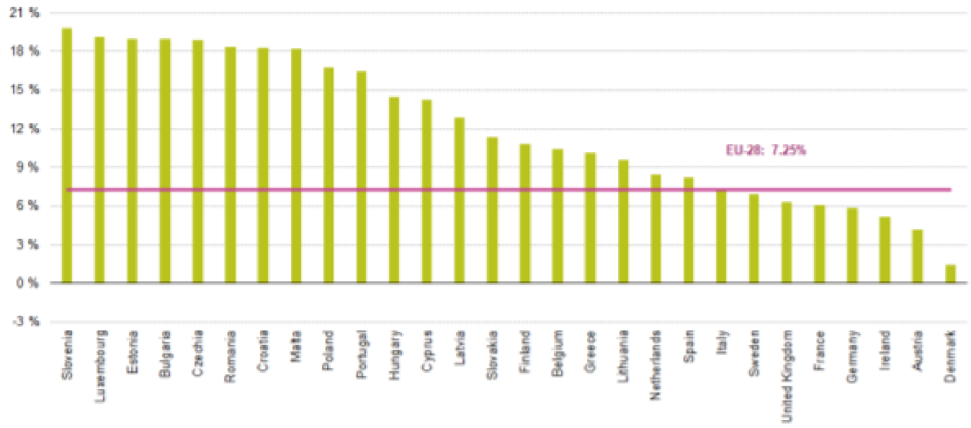

Figure 13: 2016/2017 growth in total passenger air transport by Member State (in %)

Source: ***Eurostat (2017)***

3.2 The sector of rail passenger transport - statistical data

In 2017, rail passengers showed an average of 465 billion pkm in all EU countries, with an overall increase of 3% compared to 2016. (Fig.14)

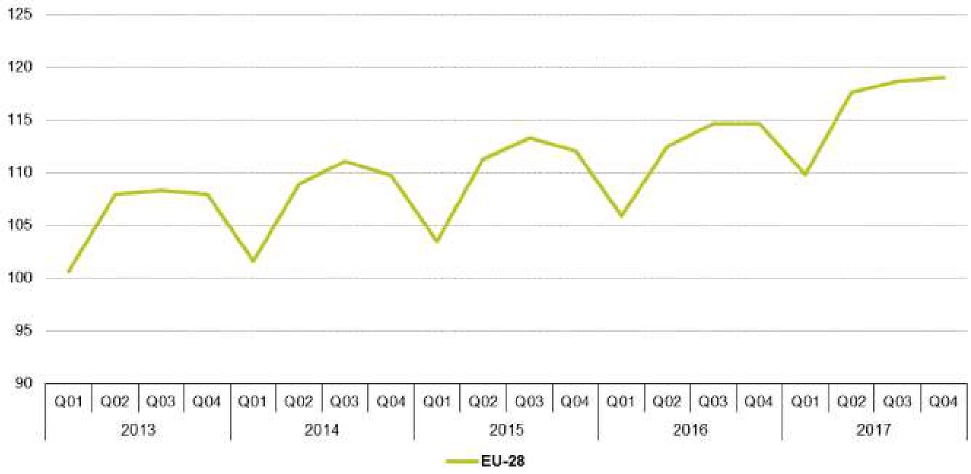

Figure 14: Quarterly rail passenger transport performance, EU-28, 2013-2017 (billion passenger-kilometers)
Source: ***Eurostat 2018***

Between 2013 and 2017, it has been observed a steady growth, in each quarter of these five years compared to the same quarter of the previous year. The second quarter of 2017 particularly influenced this increase, showing a peak of +4.5 % compared to the same quarter of the previous year. The first and fourth quarters showed a positive trend of 3.8% compared to both the corresponding quarters of the previous year and the third quarter (+3.5%).

The above figure shows a seasonal trend with decreases in the first and fourth quarters and increases in the second and third quarters compared to the previous quarter. However, in 2016 and 2017, the fourth quarter saw a slight increase of 0.1% and 0.3%, respectively, compared to the first quarter (Fig. 14).

(*EC, Railway_passenger_transport_statistics_-_quarterly_and_annual_data, 2019*)

With a particular focus on the share of domestic and international transport, domestic transport is still predominant, accounting for more than 90% of total traffic for all countries in 2017. International transport accounted for 30% of all passenger transport by rail.

4. Case study: Opportunity for city buses

In this section, a city bus case study is carried out through an economic and environmental assessment, comparing the leading energy carriers:

- Fossil fuels Diesel
- Electricity
- Hydrogen

The typical public diesel buses are widely used in the EU, and the latest generation of Euro VI buses has become significantly cleaner compared to the previous generations as a consequence of the introduced diesel-biofuel directive in the EU (Flach B., 2018).

Today, however, propulsion technologies are much diversified, and the EC started launching different projects to diversify the city bus energy carrier, promoting the use of alternative fuels. An example is a project Clean Hydrogen in European Cities (CHIC), which started in 2010 and ended in December 2016. It is a zero-emission bus project, which has distributed a fleet of electric fuel cell buses with adjoining hydrogen refueling stations in some European cities. The project successfully demonstrated that FCBs could offer a functional solution for cities to decarbonize the public transport sector, improve air quality, and decrease the noise levels.

Today, a large number of technologies and means are available for replacing internal combustion buses.

The public transport authorities can choose according to the technology that best suits their city. Hybrid buses, electric buses, fuel cell buses, hydrogen buses, natural gas buses, biofuel buses and a range of alternative fuels offer new opportunities for local emissions and sustainability. An optimal solution can be chosen, which is tailored to the specific needs of the cities. At the same time, local authorities need to make cost-efficient decisions: this is often a challenging task. There are indeed differences between bus concepts that may affect operations and costs substantially, and each bus concept has characteristics that may be optimal for one city but not for another.

4.1 Technology comparison

The Diesel buses (DBs) are working through the fuel combustion, a reaction that occurs when the fuel hydrocarbons react with oxygen to generate carbon dioxide and water.

The combustion that takes place in the ICEs does not always occur in a fully efficient way and incomplete combustion results in the emission of pollutants such as carbon monoxide and dioxide, particulate matter and soot, nitrogen oxides, sulfur oxides, and volatile organic compounds that contribute to increasing the ground-level of ozone.

Fuel quality has improved over the last decade due to lower sulfur and poly-aromatic hydrocarbon content. City buses powered by a diesel engine are fulfilling Euro VI emission standards (as of 2014).

On the other hand, electric buses run through a rechargeable battery, and the energy is stored on-board and is charged statically. Trolleybuses are commonly supplied with electricity via the overhead wires and are loaded dynamically, like with trains. Due to the low energy density of a battery compared to diesel, the autonomy of these buses is significantly smaller than for conventional buses. The battery can be recharged slowly overnight or at large intervals at the main bus depot (overnight charging) or higher frequencies along the bus line and the terminus (opportunity load).

While hydrogen fuel cell buses are powered by fuel cells that convert the chemical energy of hydrogen into electricity and deliver electrical energy into the powertrain, hydrogen is, typically, stored compressed in tanks on the roof of the bus with hydrogen refueling facilities usually located at the bus depot.

These buses produce no TTW greenhouse gases or air pollution in use; water vapor is the only tailpipe emission. Hydrogen production can be obtained from a variety of sources, including fossil fuel-based industrial processes and the electrolysis of water using renewable electricity.

4.2 Life Cycle Cost Analysis

In this Case Study, Life-cycle costing [5]has been carried out among three different buses (Diesel, Electric, Fuel cell Hydrogen), to evaluate the technologies from an economic point of view. Indeed, Life-cycle costing is a method of combining both capital (purchase cost) and operating costs (bus usage, fuelling/charging, tires, maintenance, repairs, and mileage-dependent) to determine the net economic effect of investment.

The current value of the total LCC was determined with the following equation (*Potkány M., 2018*):

$$LCC = C_A + \sum_{t=1}^{LC} C_t \, x \, \frac{(1+r)^n - 1}{(1+r)^n \, x \, r} \pm \left(NBV \, x \, \frac{1}{(1+r)^n}\right) \qquad \textbf{(1)}$$

Where:

- C_A represents the acquisition cost
- C_t is the operating costs; it is represented by the sum of fuel cost, electricity cost, maintenance costs, engine oil change cost, tire change cost in the period of Life Cycle (LC)
- discount factor/annuity present value is an indicator that reflects the time factor to net present value for an annuity (series of payments made at equal intervals) operating costs:

$$\text{Annuity present value} = \frac{(1+r)^n - 1}{(1+r)^n \, x \, r} \qquad \textbf{(2)}$$

r – discount rate (time value of money)

n – analyzed period (10 years)

- Residual price or Net Book Value (NBV): the value of the bus, taking into account diminutions, depreciation, and any amortization.

---

[5] (LCC) is a methodological approach of calculation, defined as the cost of an asset or part of it over its entire useful life cycle, while fulfilling the performance requirements.

The fuel, electricity, and hydrogen costs correspond to the average prices in 2019 in Europe: Diesel costs were set to 1,169 €/liter, electricity to 0.08 €/kWh and hydrogen to 4.9 €/kg.

The inflation rate of fuel and electricity prices was set at 1.20%, with an annual interest rate of 2.50%. Based on previous indicators, it is possible to quantify the discount rate:

Discount rate (r) = $\frac{interest\ rate \times 100}{inflation\ rate \times 100} = \frac{2.5 \times 100}{1.2 \times 100} = 2.083\%$

The present annuity value has been calculated as per formula (2):

Annuity present value = $\frac{(1+2.083\%)^{10}-1}{(1+2.083\%)^{10}\ x\ 2.083\%}$ = 8.94

Purchasing price, Energy consumption, and Maintenance costs are presented in the following table:

Table 3: LCC Comparative Analysis - Diesel, Electric and Fuel cell buses
Source: **(FCH, 2015) (Potkány M., 2018) -** *Own Table*

	Diesel bus (city bus) MERCEDES - BENZ, Merkavim Pioneer	**Electric bus** SOR-NS-12-electric	**Fuel cell** bus (IVECO Dolomitech Fue)
Acquisition cost	234.000€	577.777€	450.000€
Lifetime	10 years	10 years	10 years
Discount rate (average interest)	2,50 % p.a.	2,50 % p.a.	2,50 % p.a.
Diesel fuel/ Electricity/ Hydrogen cost with VAT	1,169 €/liter	0,08 €/kWh	4,9 €/kg
Diesel fuel/ Electricity/ Hydrogen price increase (last 10 years)	1,20%	1,20%	1,20%
Distance (per year)	72.072 km/year	72.072 km/year	72.072 km/year
Average fuel/electricity/ Hydrogen consumption	32 liter/100km	1.27 kWh/km	9kg/100km
Fuel/Electricity/ Hydrogen cost of consumption	**26.960.69 €/year**	**7.322.52 €/year**	**32.432 €/year**
Maintenance costs - tire change cost	3.300 €/ year	3.300 €/ year	3.300 €/ year
Maintenance costs - oil change	900 €/year		
Other cost			
- Repairs (brake maintenance, cleaning parts of bus)	1.600 €/year	600 €/year	1.600 €/year
- Technical Inspection	50 €/year	50 €/year	50 €/year
- Emission control	70 €/year		
- Service control	3.500 €/year	1.400 €/year	4.000 €/year
Residual value (% from the acquisition costs)	0,00%	0,00%	0,00%
LCC	**559.256€**	**691.073€**	**819.955€**

The Diesel and Electric data shown in this table are based on a study carried out in Slovakia, while for the HFCBs, the study is based on a future assumption considering the "*Fuel Cells and Hydrogen Joint Undertaking*" analysis.

Estimating 72.072 km / year and average diesel /electric / hydrogen power consumption, the operating cost of consumption provide the following results, according to the formula:

- Diesel buses: 26.960,69 €/year
- Electric buses: 7.322,52 €/year
- Fuel cell buses: 32.432,40 €/year

Applying the formula (1), LCC has been calculated for all three typologies of buses:

- for DB: LCC = 234.000 + (36.380 x 8,94) + 0 = 559.256 €
- for EB: LCC = 577.777 + (12.672 x 8,94) + 0 = 691.073 €
- for HFCB: LCC= 450.000+(41.382 x 8,94)+0 = 819.955 €

It has been assumed, that the residual price is equal to zero, due to the many kilometres ridden in ten years that are reflected in a loss of value of the asset.

In the following chart, investment and operative costs per bus typology have been showed. Even if diesel is still the cheapest option, mainly due to lower investment costs, electric buses show low operating costs due to less expensive energy and service cost. Fuel cell buses still present a high hydrogen price, since the technology is not yet mature (Fig. 15)

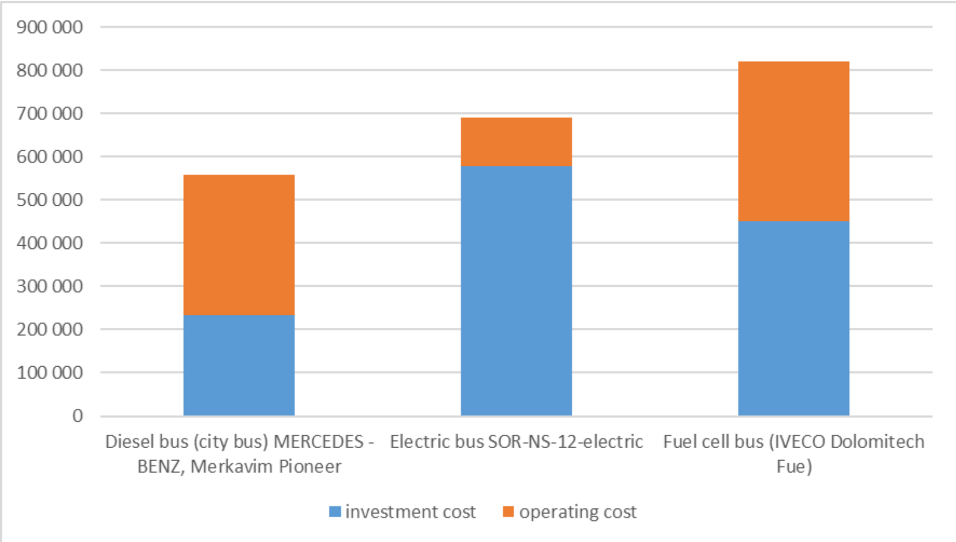

Figure 15: Life Cycle Cost Comparative Analysis (€) – Own figure

4.3 Environment Assessment

To take a look at the complete energy-chain and environmental impact of each bus technology, an LCA has been carried out. It refers to the CO_2 emissions contributing to global warming and local pollutant emissions (NOx, PM10) and the related impact on air quality in the entire lifecycle of the bus.

- TTW (Tanks to wheels, or tailpipe CO_2 emissions) refers to CO_2 emissions produced directly by vehicles
- WTT (Well to tank) refers to CO_2 emissions emitted during fuel/electricity production and distribution.
- WTW (Well to wheel) refers to CO_2 emissions produced during fuel/electricity production, distribution and vehicle use

In table 4, a comparison of GHG emission and local pollutants is showed:

Table 4: GHG emission and local pollutants of Diesel, Electric and Fuel cell buses
Source: **(Silva C.M., 2006)**– *own table*

GHG (kg CO2/km)								
Well-to-tank (GaBi)			**Tank-to-wheel (EcoGest)**			**Well-to-wheel**		
Diesel	**electric**	**Hydrogen fuel-cell**	**Diesel**	**electric**	**Hydrogen fuel-cell**	**Diesel**	**electric**	**Hydrogen fuel-cell**
0,35	0,00 Wind offshore	0,05 Wind - electrolysis	1,85	0,00	0,00	2,20	0,00	0,05
	0,71 EU mix Electricity	1,29 EU mix thermal					0,71	1,29
	0,73 Electricity NG 7000 km	2,52 NG 7000km-electrolysis					0,73	2,52
	1,47 EU mix coal	2,85 Electricity EU mix electrolysis					1,47	2,85

Table 4 shows the values of CO2 equivalent emissions obtained for each part of the fuel life cycle Diesel Electric and HFCBs. The outcomes are expressed as a function of kilometers traveled by the buses.

The combination of the results of the two models (EcoGest and GaBi) indicates that the use of diesel fuel in the bus, including its production, emits globally approx. + 1% of GHG's.

HFCBs and EBs have some advantages over ICE vehicles as, not producing any pollutant emissions directly from their operation, furthermore they are noiseless and highly efficient. Their emissions are entirely upstream, related to the production of electricity and hydrogen.

While for EBs, it is sufficient to analyze the electricity generation of the country in which it operates to achieve a complete LCA, for HFCBs, several methods can be taken into consideration for the hydrogen production.

The current dominant worldwide hydrogen production comes from non-renewable resources such as coal, oil, and natural gas. Around 95% of the produced hydrogen is from fossil fuel-based methods, and hydrogen production from water using electricity and biomass is only 4% and 1%, respectively. (Hosseini S. E., 2016)

The hydrogen production from Renewable and Sustainable Energy (RSE) on a large scale could be crucial to pursue the decarbonization path.

With the latest Euro VI, DBs technology can report lower GHG, and local emission compare to the old ICEs. The use of a particle filter on the engines and a NOx reduction system reduce GHG to 1.317 gCO_2e/km, NOx TTW until 0.8 g/km, and PM 10 TTW up to 0.015 g/km.

In contrast to fossil fuels, buses running on electricity and hydrogen produce no tank-to-wheel greenhouse gas emissions because there is no combustion taking place inside the vehicle. These vehicles have zero tailpipe emissions. Therefore, all the greenhouse gas emissions associated with these fuels occur in the well-to-tank phase, i.e., in the production and distribution of the energy sources.

WTT GHG emissions of Electric and Fuel Cell Buses depend on the energy sources, with a range between 0 and 1.474 gCO_2e/km for electric and between 0 and 2.849 gCO_2e/km for fuel cell buses. Local pollutant emissions and TTW GHG emissions are, in both cases, zero.

For electricity and hydrogen, specific production methods (coal, electrolysis) may still lead to a significant increase of the WTW GHG emissions and others (wind, solar) to a substantial decrease of the WTW GHG emissions. When the climate is an important driver, therefore, one should, certainly consider the source of the energy and the GHG emissions of the pathway.

Insights of the Study

The main advantages of the diesel bus are its high maturity, the long history of exploitation, and the well know operational performance, reliability, and costs of these buses. Focusing on the environment, electric and hydrogen buses are very clean available technologies given the local zero-emission of pollutants since the electricity can be produced from sustainable sources.

Looking at the economic part, even if DBs are still the cheapest one on the market, they are comparable with the electric ones, if we consider external costs due to air quality and climate change effects.

While electric buses have become cheaper during the last years, Fuel cell technology is not mature yet, and the investment is high, comparing diesel and electric buses. It is essential to highlight that; Technology learning shows how the initial investment will be closer and closer during the next ten years among the different technologies. The bus fleet could be renovated soon with cleaner solutions, preserving the environment, and not affecting the local budget.

5. Passengers transport by air and by High-Speed Rail: A comparative analysis

The following study compares the HST and the short-haul flights for three main European pairs, it is mainly driven by two interesting findings:

The first is that the GHG emissions caused by the short-haul flights are higher compared to the long-distance flights and the massive increase in daily flights to major European cities

According to the data released by "German non-profit Atmosfair," flying from London to New York and back generates about 986kg of CO_2 per passenger per (5.572 km one-way). Indeed, the emissions related to a relativity journey from London to Rome has an ecological footprint of 234 kg of CO_2 per passenger (1.433 km one-way). These data reveal that the ratio of kg of CO_2 to km is 8, 8 % for the route London - New York and 8, 2% for London - Rome.

It demonstrates that shorter flights are more polluting per passenger-kilometer than longer ones.

The second finding regards the exponential increase in the number of aircraft passengers, as it was discussed in the third chapter, and consequentially increase in number of domestic and intra-EU flights in the years.

As it is shown in Figure 16, between the year 2018 and 2019, the European flights increased by 1.3% (*Eurocontrol, 2019*)

The top contributor is France, with + 240 flights per day, followed by Spain that ranked second with 229 flights/day owing mainly to its flows to and from Germany (+41 flights/day), UK (+34 flights/day), Austria (+26 flights/day), Italy (+20 flights/day).

Italy has been the third contributor with 162 more daily flights, thanks mainly to its flows to and from Western Europe.

Germany ranked fourth and added 138 daily flights thanks to flows to and from Spain (+42 flights/day), Turkey (+41 flights/day), Italy (+29 flights/day) and France (+25 flights/day).

Austria was the fifth-largest contributor with 100 extra flights per day, with an 11.3% growth in local traffic mainly due to the flow from and to southern Europe (Spain +26 flights/day, Italy +12 flights/day and Greece +8 flights/day).

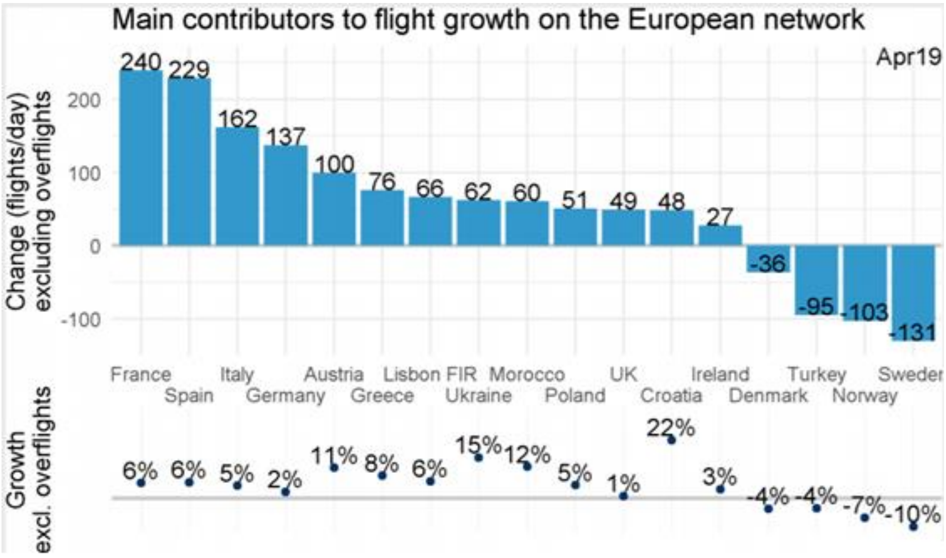

Figure 16: Main changes to traffic on the European network in April 2019
*Source: (**Eurocontrol, 2019**)*

5.1 Comparative analysis of economics and timing

The present work aims to investigate the GHG potential reduction by substituting air transport with HSR, capturing the effects induced by demand, schedule frequency, travel time, and, respectively, costs for tickets with different booking periods (a week or three months before the travel by or air).

Nevertheless, many factors contribute to the customer's choice, such as the cost of travel, safety standards and level of comfort (such as baggage weight), frequency and reliability of service and accessibility of terminals, and time efficiency.

The analysis is executed for a specific set of city pairs, Paris – London, Madrid – Barcelona, and Rome – Milan, in which more than 20 direct flights in a day were counted per each route.

For each route are captured the effects of induced demand, through the schedule frequency, the travel time per each means and the different price considering different booking period: short-term (a week before the departure date) and long-term (booking three months in advance)

Table 5: Comparative assessment HSR-AIR based on Travel time, Frequency and Return fare in purchase a week/three months before departure considering the low-cost flights – Source: ***(Trenitalia, 2019) (Ninja, 2019) (Eurostar, 2017)****- Own Table*

	travel time		frequency		Return fare purch. week before dep.			Return fare purch.3 months before dep.		
city-pair	HSR	Air* (**)	HSR	Air	HSR	Air	Air (low-cost)	HSR	Air	Air (low-cost)
Madrid - Barcelona	2h30min	1h20min	40min	30min	€ 100,00	€ 155,00	€ 51,00	€ 120,00	€ 232,00	€ 36,00
London - Paris	2h16min	1h25min	40min	50min	€ 173,00	€ 124,00	€ 48,00	€ 50,50	€ 105,00	€ 35,00
Rome - Milan	1h59min	1h10min	30min	120min	€ 65,00	€ 74,00	€ 74,00	€ 55,00	€ 38,00	€ 38,00

* +1h30min is the range time required for the securitiy check and waiting times considered for the boarding/landing (excl. time needed to reach/leave the airport)
** +3h is the range time required for security check and to reach/leave low-cost airports usually located in outskirt

The main findings shown in table 5 are:

- Travel time. Each city-pairs the high-speed rail connection is the best timing option compared to aircraft if the time required for the security check and the waiting time before the boarding/landing is considered. In this assumption are not taken into consideration the time needed to reach and leave the airports, that can change based on the means of transport that the passengers want to take to get to the airport.

In this assumption is considered: 1hours for bus, 30 min for fast trains, and 1h for a conventional train, which make different stops (which in turn result in a ticket-price difference). On the other hand, the travel time to get to the airports becomes a fundamental factor if it is combined with a low-cost flight that is usually subordinate by airline companies in peripheral airports.

- Frequency of flights/trains. For each means, the average in frequency is comparable, in an exception for the route Rome – Milan, where the high-speed train shows a higher win rate in departure time compared to aircraft mode of transport.
- Return fare purchase. From the economic perspective, in both scenarios, the leaders are the low-cost flights, follow by HSR and high-cost flights.
- With an exception in return on the fare purchased a week before the departure for the city-pair London – Paris, in which costly-flights are reflecting a better price then HSR.

5.2 Comparative analysis of energy performance and GHG emissions

Boeing 747is, the most common Boeing, with a typical seating capacity of 314 to 396 passengers, it burns approximately 10 to 11 tonnes of fuel an hour when on the cruise. It equates to roughly 4 liters of fuel every second. It can carry up to 238,604 liters of fuel.

A jumbo jet (Boeing 747-400) flying from London to New York burns about 82.353 liters of kerosene. (*flightdeckfriend, 2019*).

The cost of fuel (on the basis of 1 liter of the cost of 0.36 euros) needed to fly from London to New York is about 29,600 euros. The cost of fuel for a jumbo jet of 450 passengers, would result in about 65.8 euros per person.

This means that a short-haul flight will require more fuel per kilometer flown than a long-haul flight: for example, 75 grams of kerosene per kilometer per passenger for a 450-kilometer flight (39.705 litres/450 km - fuel consumption), compared to 33 grams per kilometer for a 1,000-kilometre flight. (38.823 litres/450 km fuel consumption)

Taking into account three major airports, Paris, Amsterdam and London, and the Milan-Rome pair, CO2 emissions were calculated for distance and fuel consumption.

The average fuel consumption on each route has been calculated based on the aircraft mix elaborated by EUROCONTROL DDR data, and it is influenced by the combination of the small regional jet (SJ) and narrow-body (NB) aircraft, which depends on the available feet of the airlines performing the service (*Eurocontrol, 2019*).

Table 6: Comparative Analysis: Average in CO2 emissions on fuel consumption and distance between train and aircraft.

Source: ***(Eurostar, 2017)***

Air routes	Avg. Fuel consumption	Avg. CO2 emission2		Distance
	Ton	ton	gCO2/PKM	km
Paris (**CDG**) - London (**LHR**)	1,75	5,51	143	348
London (**LHR**) - Amsterdam (**AMS**)	1,63	5,14	124	372
Amsterdam (**AMS**) - Paris (**CDG**)	1,88	5,91	133	400
Rome (**FCO**) - Milan (**LIN**)	2,73	8,61	128	510

As shown in Table 6, the fuel consumption is higher on the flight route Paris-London (348km distance) then London – Amsterdam (372km), in particular, the CO2 emission for shorter distances, are more relevant due to the LTO (landing and take-off) cycle that more significantly affects total consumption, whereas the CO2 emissions per pkm are in line with the fuel consumption trend.

In 2017, the international railway company Eurostar commissioned independent research to assess the CO2 per passenger produced by a Eurostar London-Paris journey compared to the emissions by a passenger on a London-Paris flight.

The study compared the journey conditions of Eurostar passengers versus the flights by aircraft, in terms of actual consumption of Eurostar electricity and the way Eurostar electricity is generated to the actual loading on aircraft and the related fuel consumption.

The conclusion was remarkable: taking the Eurostar HST to Paris instead of flying reduces CO2 emissions per passenger by a stunning 90%.

In table 7 are presented some estimated comparisons, looking at CO2 emissions of 2 major routes crossed by Eurostar. According to the latest data published on the rail company webpages, there is a significant environmental benefit of the train instead of the plan. The analysis includes two pairs London-Paris and London Amsterdam, in which are compared journey duration (hours) and the kg/CO2 emission per passenger journey:

Table 7: Comparative Analysis between plan and train CO2 Emission per passenger ($kgCO_{2eq}$) - Case of study: London-Paris and London-Amsterdam routes
Source: **Eurostar (2017) –** Own Table

CO2 emissions per passenger – Eurostar			
Journey	**Out & back by plane**	**Out & back by train**	**CO2 saving (%)**
London (King's Cross Station) - Paris (Paris-Nord)	3.5h **63,6** kg CO_{2eq}	2.75 h **4,1** kg CO_{2eq}	**93%**
London (King's Cross Station) - Amsterdam (Central Station)	4h **64,2** kg CO_{2eq}	4h **10,7** kg CO_{2eq}	**83%**

The data shown in table 7 reveal that the London (king's Cross Station) - Amsterdam Central Station is the most impacting route (per pkm), while the HSR crossing France has the best performance, due to the low-carbon intensity of electricity in France.

The CO2 emissions of HST are linked to the carbon intensity used for the production of electricity from the transport along the railways, considering the medium-voltage supply of the railway infrastructure. The specific emission factor for each section has been calculated based on the carbon intensity of medium-voltage electricity in the countries crossed by the railway.

Energy performance profile and the associated emissions for HSR transport are related to electrical units, and consequently, the emissions are a direct function of the primary energy mix of the country where the service operates.

Conclusions

City-bus

Each technology proposed for the replacement of most common diesel buses in commerce has advantages and disadvantages.

In the LCC analysis, diesel buses still reported low investment costs taking into consideration the maintenance, fuelling, and charging cost, assuming a lifetime of ten years of the bus technology.

Nevertheless, in the environmental assessment, EBs reach the primacy thanks to the "zero" GHG emissions.

Hydrogen, as a road fuel, represents a significant potential for carbon neutrality on the whole hydrogen value chain, including production and means of delivery. As well as EBs, HFCBs can achieve zero CO2 emissions along with the WTW analysis by only using hydrogen produced from renewable energy sources. One standard HFCB would save approximately 800 tonnes of CO2 in its lifetime of ten years compared to a conventional diesel bus.

It is fundamental that, in the next years, the share of renewable energy sources is increased in the overall power generation mix in all the EU Countries, to achieve an overall reduction in GHG emissions.

However, even though EBs and HFCBs show greater environmental benefits than ICEs, there are significant technological barriers, such as the limited driving range of these vehicles and the lack of a battery and hydrogen-recharging infrastructure that still prevents the widespread use of EBs and FCHBs.

For BEVs, battery technology could represent a technical barrier for public transport. There are two significant challenges: the low energy density of the batteries, which must support a reasonable autonomy, and the related disposal of them. For example, with current technology, a range of 200 km requires about 150 kg of lithium-ion batteries or more than 500 kg of lead-acid batteries.

For the FCHEVs the infrastructure represents a constraint, since the limited availability of filling stations.

For EB and FCHBs, three significant advantages were highlighted: improvement of electricity efficiency, near-zero- tailpipe emissions of GHGs, very low emission of local air pollutants.

If these barriers are removed by the mature technology and investments by municipalities in new infrastructure, then these new means of transport could take off, creating a new era of mobility of public transport by road.

Both bus technologies are incredibly valid, and there are no general criteria that define which is the best solution for each city.

The most appropriate bus option for a city depends on several factors: local conditions (regional geographical and topographical framework, climate), distance and type of route that the bus has to carry out. As well as it depends on the existence of a specific type of infrastructure (e.g. trolley network), local, regional development (technology infrastructure), availability of resources (e.g. fuels or renewable energy source for the electricity), budget and cities policies on energy security.

High-Speed Rail train vs. Aircraft on short-distance routes

As described in the previous section, the emission profile obtained from the comparative analysis shows remarkable advantages of the HSR compared to the aviation sector in terms of gCO_2 per pkm, time, and costs.

The London-Paris section (348 km) traveled by the Eurostar train showed a 93% saving in CO2 emissions.

Prices, door-to-door travel times, and some connections for HSR and air transport have been analyzed and compared.

The total travel time and price level are both important factors for passengers, and the aircraft still show a competitive price on the market compared to HST.

It is essential to apply effective market strategies and pricing promotion in combination with the punctuality and frequency of the service. If all these factors are put in place, then HST could finally increase its market share, letting this transport mode succeed.

Another benefit can be represented by having no restriction on luggage and more time flexibility, avoiding downtimes in the airport (E.g., Check-in, boarding time).

The implementation of the high-speed rail network could accelerate the switch from flights to train usage, allowing HST to compete on an equal basis with other transport modes.

List of abbreviations

BEV Battery Electric Vehicles

CAGR Compound Annual Growth Rate

CNG Compressed Natural Gas

CO2 Carbon Dioxide

EB Electric Bus

EC European Commission

EEA Environmental Energy Agency

ETS Emission Trading System

EU European Union

FAME Fatty Acid Methyl Ester

FCHV Hydrogen Fuel-Cell Vehicles

GDP Gross Domestic Product

GHG Greenhouse Gas

HFCB Hydrogen Fuel Cell Bus

HS High-Speed

HSR High-Speed Rail

HST High-Speed Train

HV Hydrogen Vehicle

HVO Hydro-treated Vegetable Oil

ICDE Internal Combustion Diesel Engine

ICE Internal Combustion Engine

Ktoe kilograms tonnes of oil equivalent

LCA Life Cycle Analysis

LCC Life Cycle Cost

LNG Liquefied Natural Gas

LPG Liquefied Petroleum Gas

Mt Million tonnes

pKm passenger per kilometer

TCO Total Costs of Ownership

TEN-T Trans European Transport Network

TTW Tank to Wheel

UNFCCC United Nations Framework Convention on Climate Change

WTT Well to Tank

WTW Well to Wheel

List of figures

List of tables

Bibliography

Agora. (2018). *The European Power Sector in 2018.*

Ajanovic A., H. R. (2016). Dissemination of electric vehicles in urban areas: Major factors for success. *Energy, 115*(2), 1451-1458.

Ajanovic, A. (2008). On the economics of hydrogen from renewable energy sources as an alternative fuel in the transport sector in Austria. *International Journal of Hydrogen Energy., 33*(16), 4223-4234.

AWG. (2019, September). *Environmental Aviation Working Group*. Retrieved from http://www.awg.aero/project/environmental/

Berger, R. (2015). *Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe - a study for the Fuel Cells and Hydrogen Joint Undertaking.*

Correa G., M. P. (2017). Performance comparison of conventional, hybrid, hydrogen and electric urban buses using well to wheel analysis. *Energy, 141*, 537-549.

Directive EU 2016/2370. (2016). Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legalcontent/EN/ALL/?uri=CELEX:32016L2370

Directive EU 2016/798. (2016). Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32016L0798

Dobruszkes, F. D. (2010). *Airline and high-speed rail competition in Europe: Towards a comeback of air transport?*

EASA. (2019). *European Aviation Environmental Report.* Retrieved from https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf

EC. (2001). *Directive 2001/16/EC*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32001L0016

EC. (2007, September 25). Retrieved from http://ec.europa.eu/transport/clean/green_paper_urban_transport/doc/2007_09_25_gp_urban_mobility_en.pdf

EC. (2009). *Single European Sky II*. Retrieved from https://ec.europa.eu/transport/modes/air/single_european_sky/ses_2_en

EC. (2011). Retrieved from European Commission (2011), White paper. Roadmap to a single European transport area - towards a competitive and resource-efficient transport system, European Commission, Brussels, Belgium.

EC. (2012, March 7). *Council Directive 96/48/EC of 23 July 1996*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2008L0057:20110322:EN:PDF

EC. (2013, January 24). Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/IP_13_40

EC. (2014, June 27). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014R0716&from=EN

EC. (2014, October 22). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0094

EC. (2015, December 7). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52015DC0598&from=EN

EC. (2016). *COM(2016)501*. Retrieved from https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-501-EN-F1-1.PDF

EC. (2016). *Regulation EU 2016/2338*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32016R2338

EC. (2016). *Regulation EU 2016/796*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32016R0796

EC. (2017). Retrieved from https://ec.europa.eu/transport/sites/transport/files/swd20170375-ertms-the-way-ahead.pdf

EC. (2017). *Rail Report 2016.* Retrieved from https://ec.europa.eu/transport/ sites/transport/fles/swd-2016-0427.pdf

EC. (2017, November 8). *Towards the broadest use of alternative fuels - an Action Plan on Alternative Fuels*. Retrieved from eur-lex.europe.eu: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0365

EC. (2018). Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018PC0277

EC. (2018, December). *RED II Directive*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

EC. (2019). Retrieved from https://ec.europa.eu/transport/themes/urban/cpt_en

EC. (2019, November). *Alternative fuels for sustainable mobility in Europe*. Retrieved from ec.europa.eu/transport: https://ec.europa.eu/transport/themes/urban/cpt_en

EC. (2019, November). *CLEAN SKY 2*. Retrieved from https://bbtproject.eu/clean-sky-2/

EC. (2019). *European Climate Change Programme*. Retrieved from ec.europa.eu: https://ec.europa.eu/clima/policies/eccp_de

EC. (2019, November 13). *Galileo Enhancement as Booster of the Smart Cities*. Retrieved from https://www.gsc-europa.eu/news/galileo-provides-boost-to-smart-transport-systems-5

EC. (2019, November 9). *Inea connecting europe facility - INNOVATION AND NETWORKS EXECUTIVE AGENCY*. Retrieved from https://ec.europa.eu/inea: https://ec.europa.eu/inea/connecting-europe-facility/cef-transport/projects-by-transport-corridor

EC. (2019). *Infrastructure and Investment | Mobility and Transport*. Retrieved from ec.europa.eu: https://ec.europa.eu/transport/themes/infrastructure_en

EC. (2019, october 20). *Railway_passenger_transport_statistics_-_quarterly_and_annual_data*. Retrieved from ec.europa.eu/eurostat/statistics-explained: https://ec.europa.eu/eurostat/statistics-explained/index.php/Railway_passenger_transport_statistics_-_quarterly_and_annual_data

EC. (2019). *Reducing emissions from aviation*. Retrieved from Climate Action: https://ec.europa.eu/clima/policies/transport/aviation_en

EC. (2019). *TEN-T Projects*. Retrieved from https://ec.europa.eu/inea/en/ten-t/ten-t-projects

EEA. (2018). Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-2

EEA. (2019, May). *Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019.*

(2019). Eurocontrol. Retrieved from https://www.eurocontrol.int/sites/default/files/2019-06/eaer-2019_0.pdf

Eurocontrol. (2019). Retrieved from https://www.eurocontrol.int/our-data#portals-to-our-data

Eurostar. (2017). Retrieved from Eurostar: https://www.eurostar.com/

Eurostat. (2018). *Statistical Pocket.* Retrieved from https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2018_en

Eurostat. (2019, March 6). *Air transport statistics.* Retrieved from ec.europa.eu/eurostat/statistics-explained: https://ec.europa.eu/eurostat/statistics-explained/pdfscache/4077.pdf

Eurostat. (2019). *Greenhouse gas emission statistics - emission inventories.*

Eurostat. (2019). *How are emissions of greenhouse gases by the EU evolving?* Retrieved from https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-4a.html

(2015). FCH. Retrieved from http://rcvt.si/uploads/rcvt/public/document/54-01_fch_ju_predstavitev_vindisar_inea_sl.pdf

Flach B., L. S. (2018). *Biofuel Annual.* Retrieved from https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual_The%20Hague_EU-28_7-3-2018.pdf

flightdeckfriend. (2019, October 6). *how-much-fuel-does-a-jumbo-jet-burn.* Retrieved from flightdeckfriend.com: https://www.flightdeckfriend.com/ask-a-captain/how-much-fuel-does-a-jumbo-jet-burn/

Hosseini S. E., A. M. (2016, May). Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development. **Renewable and Sustainable Energy Reviews, 57, 850-866.** Retrieved from https://doi.org/10.1016/j.rser.2015.12.112

ITF. (2019). *ITF Transport Outlook 2019.* Paris: OECD Publishing,. Retrieved from https://doi.org/10.1787/transp_outlook-en-2019-en.

Journal, N. (2013, January 25). Retrieved from http://www.ngvjournal.com/s1-news/c4-stations/eu-launches-clean-fuel-strategy-aimed-at-reinforcing-refueling-network-in-europe/

LNG World News. (2019, August). Retrieved from https://www.lngworldnews.com/eu-launches-clean-fuel-strategy/

Ninja, R. (2019). Retrieved from rail.ninja: https://rail.ninja/

OMV. (2019, July). *Hydrogen*. Retrieved from https://www.omv.com/en/wasserstoff

Potkány M., H. M. (2018). Comparison of the Lifecycle cost structure of Electric and Diesel buses. *Naše more, 65(4)*, 270-275.

Prussi M., L. L. (2018). Passenger Aviation and High-Speed Rail: A Comparison of Emissions Profiles on Selected European Routes. *Journal of Advanced Transportation, 2018*.

Regulation EU 2016/2337. (2016). Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32016R2337

S2R-a. (2018, August). Retrieved from https://www.shift2rail.org

Scheffer, S. (2019). *Aviation tracking Clean Energy Progress IEA.*

Silva C.M., G. G.-L. (2006). A tank-to-wheel analysis tool for energy and emissions studies in road vehicles. *Science of the Total Environment, 367*(1), 441-447.

(2019). Statistical Pocket OECD ITF Transport Outlook. Retrieved from https://read.oecd-ilibrary.org/transport/itf-transport-outlook-2019_transp_outlook-en-2019-en#page31

Sun X., Z. Y. (2017). Air Transport versus High-Speed Rail: An Overview and Research Agenda. *Journal of Advances Transportation, 2017*.

Trenitalia. (2019). Retrieved from trenitalia.com: https://www.trenitalia.com/it.html

UN, U. N. (2017). *Trans-European Railway High-Speed.* Retrieved from https://www.unece.org/fileadmin/DAM/trans/main/ter/terdocs/TER_High-Speed_Master_Plan_Study.pdf