„Investigation of smart city concepts to improve emission-free mobility – The example of the city of Cologne "

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Abstract

In today's society, issues such as climate change and resource scarcity are of great importance. What can be done to mitigate climate impacts and make our world more environmentally friendly and innovative? Smart City is a term that has not yet been uniformly clarified. But it is clear that cities which are developed or built according to Smart City concepts are significantly more environmentally friendly, efficient and digitally positioned.

Cologne is the fourth largest city in Germany and is a pioneer in topics such as the expansion of emission-free mobility, especially in public transport. In addition, several smart city projects that the city has carried out with cooperation partners are considered innovative projects with a promising future. However, there is a large amount of traffic in million inhabitants city, which repeatedly leads to concentrations of air pollutants that exceed the limit values. One key focus of the city is reducing traffic and thus reducing air pollutants at the same time. As part of its Green City Master Plan, numerous measures have been initiated that have successfully improved the air quality and reduced traffic. The first steps of a smart city development have been developed and implemented and will be further advanced in future. Cologne proved to be the ideal city for the thesis of this work: "Investigation of Smart City Concepts for the Improvement of emission-free Mobility - The Example of the City of Cologne".

INTRODUCTION

The thesis "Investigation of Smart City Concepts for the Improvement of Emission-free Mobility - Using the Example of the City of Cologne" presents itself as relevant in (climate) policy, the automotive industry, the health sector and the future development of logistical processes. Especially the climate and energy policy of the European Union (EU) as well as the climate protection law of the Federal Republic of Germany represent the most important basis for the development of climate targets. In the Paris Climate Agreement of 2015, many countries set themselves the goal of limiting global warming to a maximum of 1.5 degrees Celsius. In addition, the EU has set binding climate protection targets for all member states and binding actions. These include the goal of planned climate neutrality by 2050, meaning to avoid almost all greenhouse gas emissions as possible in the European Union. The EU heads of states and governments have developed an additional target under which all greenhouse gas emissions within the EU are to be reduced by at least 55 percent by 2030 compared with 1990 levels. The so-called European Green Deal is intended to support the goal of climate neutrality by 2050 to the extent that the economy within the EU becomes climate-neutral and more resource efficient. These Green Deal actions touch base on climate, environmental and biodiversity protection, as well as mobility and industrial policy, and incorporate specifications for energy, agricultural and consumer protection policy. The European Union's main climate protection instruments for reducing greenhouse gas emissions consist of EU emissions trading on the one hand and the EU climate protection regulation on the other. Emissions trading specifically affects the energy sector and industry, whereas the climate protection regulation particularly affects the sectors of transport, buildings, agriculture and small industrial plants.[1]

Nationwide, the Climate Protection Act is considered authoritative for all greenhouse gas emission reduction targets and measures. Since August 31, 2021, the climate protection targets in Germany have become more stringent. By 2045 greenhouse gas neutrality should be accomplished and emissions are to be reduced by 65 percent by that year compared to 1990. The law also emphasizes strengthening natural sinks. This means that unavoidable residual emissions are to be diverted to so-called natural sinks, such as forests and peatlands, as these can bind greenhouse gases naturally.[2]

One of the more recent decisions of the EU Environment Council is that from 2035, newly registered vehicles will no longer be allowed to emit CO2. The so-called fleet limits for passenger cars need to be reduced to zero. The automotive industry is already responding to the climate targets set by policymakers by increasingly developing alternative drive technologies, such as fuel cell and electric vehicles, and addressing the health aspects of, for example, particulate pollution in vehicle interiors through certain filter systems. The continuation of combustion engines powered by alternative fuels such as eFuels, has also been considered as these do not release CO2. All vehicles registered before 2035 will be protected, and trade in used cars will remain permitted. Originally, the legislative process in the European Parliament should have been completed by the end of 2022, but the final conclusion of the process has been postponed indefinitely.[3]

In conclusion, it can be said that the specified climate targets of the EU but also of the Federal Republic of Germany have a major impact on the various smart city concepts and strategies and will continue to do so in the future.

METHODIC AND STRUCTURE OF THE MASTER THESIS

The Secondary research methodology is used to compare different research approaches and theories on the topic and to identify research gaps where appropriate. All reputable scientific literature, research, studies and articles serve as sources. This thesis explains various terminologies first before looking at current climate policy, especially in relation to greenhouse gas emissions and changes in the automotive industry. The theoretical part of this thesis deals with Germany-wide data and values on demographic change, infrastructure, especially in the field of mobility, as well as environmental and health problems as an effect of noise, air pollution and traffic. It also covers the development and expansion of zero-emission mobility and the various smart city models and types, before drawing a connection to the city of Cologne in the analysis section and illustrating how Germany-wide values can be put into relation with a city of millions. In addition, the problems of the city of Cologne in the context of the Smart City concept are brought into focus. All significant figures, data and facts on the topic of emission-free mobility and Smart City in Cologne will be summarized, analyzed and explained. It then examines the extent to which the city of Cologne has implemented its Smart City concept to date and what improvements or deteriorations have occurred. The opinions of citizens and local politicians are considered as well. In the last part of this thesis, the collected results are summarized in the analysis with the help of the theoretical part and related to this thesis. A conclusion completes the final part of this thesis.

SMART CITY TYPES, CONCEPTS AND GOALS

As a rule, a distinction can be made between two smart city types. On the one hand, there are cities that are developing into smart cities by integrating and implementing their own smart city concepts in the already existing city. This applies to all cities that are not completely new. On the other hand, there are smart cities that did not exist before and were built completely new and are smart based by concept. This form exists very rarely, however, "Masdar City" in Abu Dhabi is a good example of this type of smart city. Masdar City was built completely new and based on a Smart City concept in the middle of the desert.[4]

Smart City concepts refer to the digitalization of individual areas of smart city development. In addition to the list in Chapter 2.1, other areas are also included in smart city concepts, such as smart education, smart infrastructure, smart administration and smart water and wastewater supply.[5] An example of a project around smart mobility would be the so-called "Parkpilot" of the city of Cologne, which facilitates the search for parking spaces with digital support; this smart city project is discussed in more detail in Chapter 4.2. Another project in the area of Smart Infrastructure would be the expansion of Park and Ride parking spaces in several urban areas.[6] The goals of a Smart City are to facilitate the daily lives of a city's residents in a more climate-friendly, efficient, and timely manner. For the cities themselves, however, the economic aspect is also important in order to remain competitive with other cities. At the same time, aggravating factors such as population growth, ongoing demographic change, pollution, and a city's diminishing resources, among others, are countered with smart city projects. These include the car and bike sharing services already established in many cities, but also digital advances in all areas of a city.[7]

PROBLEM

Common problems in cities are air pollution, noise and traffic. This thesis is about the investigation of smart city concepts to improve emission-free mobility. In this respect, cities need individual and concrete Smart City concepts to create more climate neutral cities and thus enable the same or even better options or courses of action of today for future generations. Furthermore, the question is raised when smart city concepts reach their limits in terms of feasibility and to what extent combustion engines are related to the problems of smart city concepts. Specifically, the implementation and planning of Smart City will be addressed using the example of the city of Cologne with an increased focus on zero-emission mobility.

A. Demographic change

This section deals with demographic change in Germany and the associated problems. Figure 1 illustrates the population density of Germany in 2020, showing that the pink areas have up to 50 inhabitants per km², the light pink areas have 50 to 100 inhabitants per km², the light blue areas have 100 to 150 inhabitants per km², the aquamarine areas have 150 to 200 inhabitants per km² and the dark blue areas have 200 and more inhabitants per km². Accordingly, the uneven distribution of the population is recognizable. Most of the German population lives in large cities. It can also be said that the northeast of Germany is sparsely populated, apart from Berlin and the surrounding area. With 69 and 85 inhabitants per km², respectively, Mecklenburg-Western Pomerania and Brandenburg have the lowest population density of all the German states. The situation in the west and southwest of the Ruhr region is quite the opposite, with several highly populated areas lined up next to each other. These are part of the so-called "blue banana", which extends across several EU countries in a band of densely populated urban areas with up to 3,000 inhabitants per km².[8]

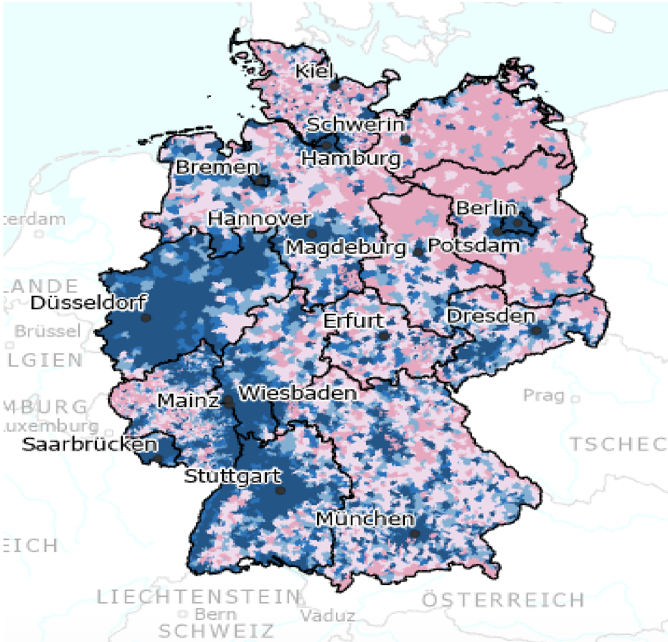

Fig. 1. Population density Germany in 2020 [9]

B. Internal migration

The outward and inward migration within Germany is also referred to as internal migration. Compared with previous years, Brandenburg had the highest number of in-migrants in Germany in 2021. Baden-Württemberg, on the other hand, recorded the most outward migration. As noted earlier in this chapter, there is a strong urbanization in Germany, which is constantly increasing, which in turn ensures a continuous change in the real estate market.[10]

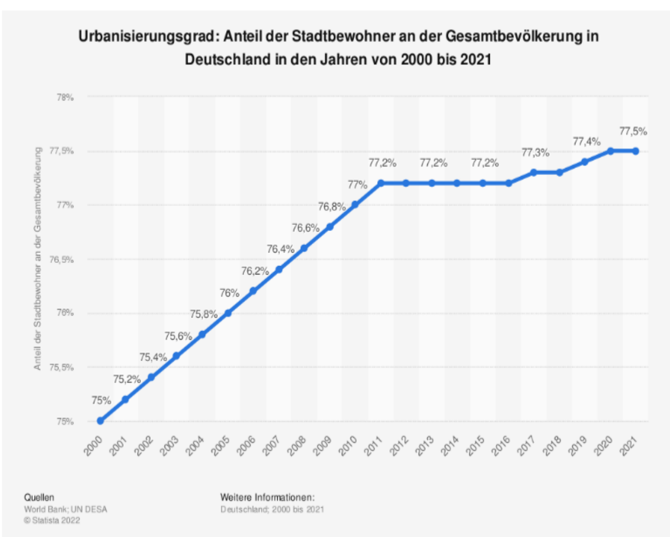

Fig. 2. Degree of urbanization: share of urban residents in the total population in Germany in the years from 2000 to 2021 [11]

Figure 2 once again illustrates the development of urbanization in Germany from 2000 to 2021. Here, it can be seen that a total of 77.5% of the German population will live in cities in 2021.[12] However, there are also some commuters living in German cities and in the countryside who want to avoid moving because of their living situation or living environment. Commuters are people who cross the border of a municipality or city for work. In total, about 19.6 million people commuted between home and work in 2019. Thus, approximately 59.5% of employees subject to social security contributions do not work at their place of residence. Compared to 2009, the proportion has risen to around 22.5%.[13] A survey with a total of 3,173 respondents showed that around one third of city dwellers are commuters. In rural areas, on the other hand, the proportion of commuters was around 58%. This difference can be attributed to the mobility within the city and the countryside, as there are significantly more options for getting around in the city, such as public transport, car and bike sharing, and e-scooters.[14]

C. Infrastructure Germany

This chapter deals with infrastructure and the associated emissions in Germany. The transport sector is one of the most climate-damaging sectors in Germany. Compared to other sectors, the transport sector does not contribute to climate protection and is stagnating in its development. In 2019, transport emitted a total of 165 million tons of CO2, a level similar to that in 1990. However, passenger and freight traffic in Germany in particular is growing continuously, resulting in a total transport effort of 1,169 billion passenger kilometers in 2019. Compared with 1990 (875 billion passenger kilometers), this represents an increase of around one third. As mentioned above, the transport sector is one of the main contributors to emissions with a total of 96%, of which road transport by passenger cars accounts for about 60% and freight transport for about 35%. In summary, not only have daily per person kilometers quadrupled since 1950 (9 km) (2017: 39 km), but the general mileage of motor vehicles, both passenger and freight, has increased by 31% since 1991.Another reason for the increase in road traffic is also the increase in the number of passenger cars in recent years. In 1950, there were only 11 cars per 1000 inhabitants, in 1970 there were 213, and in 1990 there were already 385 cars per 1000 inhabitants. The peak was in 2019 with a total of 574 cars per 1000 inhabitants.[15]

In order to counteract the problems of the transport sector, such as lack of parking space, traffic jams, air pollution and increased greenhouse gas emissions, especially in large cities, there have been more and more offers of so-called car and bike sharing for several years. For many city dwellers, car sharing offers a good alternative to owning a car.

D. Environmental and health problems

In this chapter, the effects of greenhouse gas emissions, noise pollution, particulate matter pollution and the waste problem on the environment and the health of people in German cities are addressed. In 2021, greenhouse gas emissions in Germany increased again. Thus, around 750 million tons of greenhouse gases were released. Compared with 2020, this is around 33 million metric tons, or 4.5% more greenhouse gases released. Overall, however, a reduction of 38.7% in greenhouse gas emissions can be recorded compared with 1990. The increase in 2021 can be largely attributed to the energy sector, as the demand for electricity has increased, the gain from renewable energy has decreased, and the increase in the price of gas has led to increased generation of electricity from coal-fired power plants. Electricity generation from renewables has decreased by approximately 7% due to poor wind conditions.[16]

Within large cities, however, there are other factors that can strongly influence the health of the people living there. These include noise pollution, for example from heavy traffic, and the aforementioned air pollution caused by increased particulate matter, among other things. Ambient noise has a proven impact on people's health. There are five main sources of noise: road traffic, rail traffic, air traffic, noise from wind turbines and noise from leisure activities.[17]

As mentioned above, fine dust pollution is also one of the factors that are harmful to health, especially within cities. Depending on the diameter of the fine dust, the health effects also differ. The smaller the fine dust, the more harmful it is to health, since the probability that it will be exhaled again or recognized by the lungs' own cleaning cells decreases. Research was conducted primarily on fine dust particles with a diameter of 10 (PM10) and 2.5 micrometers (PM2.5). So-called ultrafine particulate matter with a diameter of less than 100 nanometers (PM0.1) has been less well researched to date [18], as the necessary measurement technology was not yet fully developed.[19]

Development and improvement of drive technologies

This chapter addresses the further development and improvement of internal combustion engines and alternative drive technologies such as electric and hydrogen mobility. In 2022, there were approximately 31 million gasoline-powered passenger cars in Germany. The number of diesel vehicles amounted to approx. 15 million. Other types of drive such as hybrid (approx. 1.5 million) and electric vehicles (approx. 618,000) account for a smaller share.[20]

In the following section, the CO2 emissions of the various drive technologies (gasoline, diesel and electric vehicles) are considered. Passenger cars currently account for the majority of CO2 emissions in the transport sector, at more than 60%. A diesel vehicle produces 2.64 kilograms of CO2 per liter. A gasoline-powered passenger car emits 2.33 kilograms of CO2 per liter each. On average, a gasoline-powered passenger car consumes about 143 grams of CO2 per passenger kilometer (assuming 1.5 people in the car). On average, a diesel-powered car emits about 5% less CO2 than a gasoline-powered car. Since fuel consumption varies from vehicle to vehicle, no general statement can be made about the amount of CO2 emitted by combustion vehicles. However, it can be assumed that the emissions of a diesel vehicle are lower on average than those of a gasoline-powered passenger car. The emission of nitrogen dioxide, however, is significantly higher compared to a gasoline-powered passenger car.[21]

For some years now, the automotive industry has been intensively addressing the issue of emissions reduction. The main focus here has been on improving existing drive technologies in terms of internal engine solutions, for example by reducing fuel consumption. In addition, the focus was also on the so-called exhaust gas aftertreatment, which is characterized by the installation of catalytic converters and particulate filters. In the meantime, these parts are also part of the standard equipment of most vehicles to ensure a reduction in consumption and emissions.[22]

The number of electric cars in Germany has been rising steadily since 2012. While there were around 4,541 vehicles in 2012, there were already 12,156 electric cars on the roads two years later. The biggest increase occurred within one year between 2021 and 2022. On January 1, 2021, there were around 309,083 electric cars on the roads, while on January 1, 2022, there were already 618,460 electric cars. This is partly due to the financial support provided by the government for new purchases or leasing. From 2023, electric vehicles will be subsidized by up to 4,500 euros if the net list price of the basic model does not exceed 45,000 euros.[23]

For the production of hydrogen, the so-called steam reforming process is currently mainly used. The disadvantage here is the increased release of carbon dioxide. On average, this process produces around 10 to 15 kg of CO2 per kg of hydrogen (H2).[24] Just as with an electric car, no CO2 emissions are produced during the journey.[25]

The use of raw materials in production and the recycling potential of the various drive technologies are explained in more detail in the following section.

There are two main methods for recycling end-of-life vehicles in Germany. On the one hand, vehicles are exported as used cars and, on the other, end-of-life vehicles are dismantled and subsequently scrapped. In 2019, there were about 2.5 million used cars exported abroad. In the recycling of internal combustion engines, a total of 93.6% of end-of-life vehicles were recycled in 2019.[26]

The rare raw materials lithium, cobalt and platinum are required in the production of a battery for an electric vehicle. Due to the rarity of these raw materials, it is of great importance to recycle them after use. Compared to combustion vehicles, electric cars have a much lower proportion of parts, which also leads to a saving of other raw materials.[27] The production of the fuel cell (PEMFC) requires raw materials such as platinum and graphite. These are needed for the production of the catalyst and the so-called bipolar plates. The same measures apply for reliable recycling as for other drive technologies.[28]

The next section explains the service life of the drive technologies discussed. Internal combustion engines have been around for more than 100 years, and since the engines are constantly being developed further, their service life is high. However, this depends heavily on the availability of the necessary spare parts. The carbon footprint of an electric vehicle, as explained above, has never been as good as expected. Due to the electricity mix in Germany, CO2 emissions are taken into account, as well as the energy-intensive production of the batteries. In addition, older studies have pointed to the short life span of batteries, which in turn was included in the carbon footprint.[29] Today, general assumptions about the battery performance of electric vehicles suggest a capacity of 70% after 80,000 km. The battery of a Tesla, on the other hand, had a battery capacity of 85% after 165,000 km. [30] In addition, there are now electric cars that have a mileage of around 700,000 kilometers.[31] Even after the battery has exhausted its mileage, it can still be used in other ways. For example, by using it as a stationary power storage unit. As production processes are constantly being adapted, the energy required to manufacture the battery has now been reduced, and so has the carbon footprint of an electric car.[32]

SMART CITY COLOGNE PROJECTS

In order to better support the thesis of this project "Investigation of Smart City Concepts for the Improvement of Emission-free Mobility - Using the Example of the City of Cologne", the development of the Smart City Cologne, the fields of action, the partners and the Smart Mobility projects of the city of Cologne will be presented in the following. Smart City Cologne is an initiative of the City of Cologne in cooperation with Rhein Energie AG, which was founded in 2011. Originally, the focus of Smart City Cologne was on the idea of "climate protection through innovation". In the meantime, the fields of action have been expanded to include mobility, the economy, and a general change in transportation. Nevertheless, the focus of the initiative should remain on climate protection because this ensures the quality of life in many areas for the residents. Together with the citizens and partners from the business sector, Smart City Cologne wants to make its city innovative and efficient, especially in the areas of climate, energy and traffic management. Smart City Cologne started with five own projects and called on other companies and actors of the urban society to participate with projects as well. In principle, anyone can participate: private individuals, associations, companies and initiatives.[33] Furthermore, climate projects can be carried out as individual activities or in cooperation with others. The Smart City Cologne GO and RheinStart funding program finances plans and projects by private individuals, educational institutions, associations, companies and start-ups.[34] The funding program provides for Smart City projects to be subsidized by up to 80%. However, the total cost of the project must not exceed 12,500 euros. Currently, however, the funding program is suspended and no new applications are being accepted.[35]
The following Smart City Cologne projects were examined in more detail in this thesis:

- “Landstrom-Smarte Energie für Schiffe “
- “Co2-freie Paketzustellung mit StreetScootern”
- “ParkPilot-Projekt”
- “Klimastraße Neusser Straße”
- „Köln steigt aufs Rad“
- “Taxiladekonzept für Elektrotaxis im öffentlichen Raum”
- „Smart City KVB“
- “Mitfahr-App goFLUX”
- “Mobilitäts Cockpit Köln – innovativ, integrativ und intelligent”

GREEN CITY MASTER PLAN: MEASURES OF THE CITY OF COLOGNE

In order to improve the development of sustainable mobility in municipalities and reduce pollutant emissions at the same time, the so-called Green City Master Plan was funded by the German Federal Ministry of Digital Affairs and Transport. The topics to be prioritized in the Green City Master Plan are, digitization, and electrification of transport, as well as cycling, urban logistics and networking in public transport. A significant element of the "Clean Air 2017-2020" program is the funding guideline "Digitization of Municipal Transport Systems" from the Federal Ministry of Digital Affairs and Transport. The funding to support the master plans amounted to 12 million euros.[36]
The following actions were taken as part of the Green City Master Plan of the City of Cologne:

- “Ausbau des Radverkehrnetzes”
- “Erweiterung des Kölner Leihradsystems”
- “Parkraummanagement – Bewohnerparken”
- “Ausbau von Park and Ride-Plätzen”
- “Durchfahrtsverbotszone für LKW ab 7,5t”

ECONOMIC VIEW OF SUSTAINABLE DRIVE TECHNOLOGIES

In the following chapter, a cost analysis of the various drive technologies is explained using the Total Cost of Ownership (TCO) calculation method. In addition, the gasoline-powered "BMW 330i x Drive", the electric car "Tesla Model 3 Long Range", and the fuel cell vehicle "Toyota Mirai" are compared in a linear projection over 13 years. The TCO calculation method represents an all-encompassing method for the economic evaluation of different drive and power plant types. This is because it takes all the costs of acquisition into account, use and maintenance that are relevant to the complete service life of these vehicles. In order to enable a fair comparison between the above-mentioned vehicles, it is necessary to calculate the total cost of ownership, because there are large differences in acquisition and variable costs depending on the type of drive. The most important cost parameters when calculating the total cost of ownership of passenger cars are acquisition costs, maintenance and repair costs, fuel costs and specific fuel consumption, the service life of the vehicle, annual mileage and insurance costs.[37]
Table 1 provides an illustration of the above cost parameters and their associated figures depending on the model. All values for this TCO calculation are derived from the car manufacturers themselves or from major car insurance companies. Costs for MOT and parking are not included in this calculation. For the Tesla, it can be assumed that it will drive 14,000 kilometers over a period of 13 years and that at least 70% of the battery capacity will be maintained. This means that the battery will need to be replaced after 8 years only or after 192,000 kilometers of driving. The Tesla and the Toyota Mirai are subsidized by the environmental bonus of 4,500 euros, which is paid by the state. In addition, the vehicle tax for electric and fuel cell vehicles is tax-free for ten years. These advantages are clearly reflected in the bottom line of the two models. The fuel costs per liter of gasoline and per kilowatt of electricity shown in the table are average values. The price per kilowatt for hydrogen is the current price (as of March 2023). The cost comparison of a full tank in the upper middle class shows that a full tank in the Toyota Mirai costs 77.56 euros. The Tesla's full tank costs about 36.75 euros at an average value of 0.49 kwh, and the BMW's full tank costs about 103.25 euros at a price per liter of 1.75 euros. In terms of range, the BMW has a

clear advantage with around 800 kilometers. However, its annual maintenance and repair costs of around 804 euros are far higher than those of the other two models. Emissions are also a clear disadvantage for the BMW. In summary, it can be said that according to this TCO calculation, not only are the acquisition costs of the Tesla the lowest, but also the running costs over a year are the most favorable at 2,929.90 euros. Thus, the Tesla Long Range model would be the most cost-effective and environmentally friendly choice in this comparison.

	Toyota Mirai	Tesla model 3 long Range	BMW 330i x Drive
Anschaffungskosten in (€):	ab 65.990 €	ab 53.990 €	ab 56.100 €
EU-Fahrezugklasse:	Obere Mittelklasse	Obere Mittelklasse	Obere Mittelklasse
Antrieb:	Wasserstoff	Elektrisch	Benzin
Co2-Emissionen:	0 g/km	0 g/km	158 g -175 g/km
Umweltbonus:	4.500 €	4.500 €	0 €
Reichweite bei Volltank:	~ 650 km	~ 602 km	~ 800 km
Wartungs und Reperaturkosten pro Jahr in (€):	~ 375 €	~ 252 €	~ 804 €
KFZ-Steuer pro Jahr in (€):	74 € (letzten 3 Jahre)	68 € (letzten 3 Jahre)	168 €
Tanken pro kg/ Laden pro kwh/ Tanken pro liter:	13,85 pro kg	0.49 €/kwh	~ 1,75 €/l
Tankgröße/Bateriekapazität	5,6l	75 kwh	59l
Kraftstoffverbrauch (auf 100 km):	0,79kg-0,89kg	14,7 kwh	7,0 l -7,8 l
Lebensdauer des Fahrzeugs:	13 Jahre	13 Jahre	13 Jahre
Versicherungskosten (Vollkasko im Jahr):	~ 2.000 €	~ 2.000 €	~ 2.000 €
Jahresfahrleistung:	14.000 km	14.000 km	14.000 km
Kosten in einem Jahr in 14.000 km:	3.674,78 €	2.929,90 €	4.784,93 €
Kosten nach 13 Jahren:	47.772,14 €	38.088,70 €	62.204,09 €

Table. 1. TCO Vehicle Compare

GOELS AND VIEW

In addition to the Smart City projects that have already been implemented, the city of Cologne also has other goals and visions that should lead to the implementation of emission-free mobility and the reduction of motorized individual traffic in the inner-city area. For the Green City Master Plan actions, the city has set itself the goal of implementing all measures or optimizing existing measures by 2030. A major goal of the city is the development and expansion of public transport, especially in commercial areas. The share of commuter traffic in these areas is more than 20 %, and commuters in particular use motorized individual transport more often than average. Furthermore, additional cycle paths are to be extended within commercial areas and further cycle traffic concepts for the respective districts are also to be completed by 2030. Moreover, the city would like to generally optimize the conditions for the job ticket so that more people have the opportunity to use a job ticket. Cologne's footpaths should not be ignored either; the city is planning footpaths with barrier-free access as well as the expansion of pedestrian paths in commercial areas for a safe connection to public transport. In the long term, individual motorized traffic should become emission-free. Legal requirements are not the only relevant factor here, as the city of Cologne claims electrification of passenger cars, even in itself. To this end, the city is aiming for a car combustion rate of around 75% by 2030, and this rate should then be 25% by 2040. In addition, the expansion of charging infrastructure in Cologne is to be expanded. Here, the city is following the recommendations of nationwide studies. Accordingly, around 3,200 charging stations are to be present in the city by 2030. By 2040, the number of charging stations is to expand to 12,800. [38]

Especially at locations where people stay for temporary periods, such as the parking lot at the supermarket or indoor swimming pool, as well as the stay at mobility stations.[39]

The city of Cologne has focused on several goals within the scope of its parking space management. First, parking fees are to be increased in conjunction with inflation and public transport ticket prices. Second, 5% of all car parking spaces in public spaces are to be eliminated by 2030. In addition, there will be more neighborhood garages in new development areas to relieve the parking situation in public spaces. In addition, a so-called mobility station with around 5,000 parking spaces is to be built on the parking areas of Koelnmesse outside trade fair times. This will create a new hub that will relieve inner-city traffic and offer further environmentally friendly options for connections to the city center. In the logistics sector, the city is planning to convert freight forwarding trucks and industrial trucks from diesel to hydrogen in the Port of Cologne. The city has set itself the goal of operating 100 trucks and 14 industrial trucks on hydrogen by 2040. However, certain framework conditions must be observed for this, such as the provision of subsidies for the development of a filling station infrastructure as well as financial subsidies, among other things. In addition, some of the container and trailer transports are to be transferred from the road to the rail network. Several transshipment terminals will need to be built for implementation, which in turn will require political support. In addition to the numerous goals, the city of Cologne also has a number of visions but concrete implementation timeline is still pending. One of the city's visions is the introduction of a 30 km/h speed limit throughout the city. Furthermore, city toll is considered, in which the city center, apart from buses, cabs, as well as business, delivery, and construction traffic, is to become car-free by 2030. By 2040, this city toll would then be applied to the entire city area. The revenue generated from this is to be used for public transport. In addition, all streets with two MIV lanes are to be tested to see if a conversion would be possible. The focus here is on expanding one lane each for bicycle and e-scooter traffic.[40]

Conclusion

Based on the results obtained from the analysis, the thesis of: "Investigation of Smart City concepts for the improvement of emission-free mobility -The example of the city of Cologne", can be justified in many ways. One of the goals in the Paris Agreement, was to limit the global temperature increase to 1.5 degrees Celsius by 2030 and to reduce emissions worldwide. As of now, this goal is still out of reach, despite constantly improved technology in all sectors and optimized drive technologies, a total of about 750 million tons of greenhouse gases were emitted in 2021, which corresponds to a reduction of about 38.7% compared to 1990. In order to achieve the targets, set out in the Paris Agreement, Germany would have to be climate-neutral by 2035. This is unlikely, yet the EU Environment Council has taken a first major step towards achieving this goal. Starting in 2035, no new cars with CO2 emissions are to be registered in the EU. Cologne is considered a city in which diversity and tolerance are lived, and not only that has made it interesting as an example for this work. Also, the steady growth of the fourth largest city in Germany was relevant for the selection. Cologne's transport sector emits around 26 % of greenhouse gas emissions. The per capita greenhouse gas emissions of 9.4 tons are below the national average of 10 tons. To achieve the climate target by 2030, per capita greenhouse gas emissions would have to be 6.4 metric tons, which would be 50% less than in 1990. In order to achieve the planned climate goals and to increase the quality of life of the citizens of Cologne, the Climate Protection Coordination Office of the City of Cologne founded the Smart City Cologne initiative in cooperation with RheinEnergie AG. Smart City Cologne presents smart Cologne projects initiated by citizens, companies or the city itself. In addition, Smart City Cologne networks and initiates cooperations with new and existing partners. It is important that Smart City Cologne is open to everyone and should be considered a local network. Smart City Cologne GO is the city's funding program, which financially supports Smart City projects under certain conditions from 2019 to 2023. In addition to the official Smart City Cologne website and the Smart City Cologne conference, the initiators are very keen to share all projects as transparently as possible with Cologne citizens and cooperation partners. In this paper, only the Smart Mobility projects of the city of Cologne were taken up. The Schiffs-TankE, was the first Smart City project of Rheinenergie AG. The aim of this project is to supply ships with electricity via Schiffs-TankE, so that the harmful diesel generators do not have to continue running. The energy supply of the ship's TankE consists of renewable energies. With a total of seven systems, a total of 25 tons of CO2 have been saved since 2019. This was followed by the DHL Group's project for emission-free parcel delivery with the help of StreetScooters. Since 2016, a total of 66 StreetScooters have saved around 200 tons of CO2 in Cologne. To date, around 1.6 million tons of CO2 have thus been saved in Cologne. The scooters are charged using green electricity at several charging points in various parts of Cologne. DHL also plans to be completely climate-neutral by 2050. The ParkPilot is another smart city project located around the climate street Neusser Straße in the Cologne district of Nippes. With the help of sensors and artificial intelligence, the ParkPilot detects when and where one of the approximately 800 parking spaces becomes available. The whole service is free of charge and also ensures that traffic on Neusser Straße has dropped by 30%. Neusser Straße is also considered a climate street because the stores located there as well as all streetlights are equipped with LEDs by Rheinenergie AG. Thus, 55% of energy and 5 tons of Co2 could be saved. The "Köln steigt aufs Rad" project was funded by the Smart City Cologne Go program in 2019. The goal was to motivate as many Cologne residents as possible to ride their bikes. Another supporter was the app Radbonus, which could be used to "earn" vouchers from local stores. Around 700 people from Cologne got on their bikes and cycled around 62,000 kilometers, saving around 8,000 kilograms of CO2. The campaign still takes place every year. The pilot project " Taxi Ladekonzept für Taxis im öffentlichen Raum ", TALAKO for short, was launched in October 2019.

Fig. 3. Talako charging station at Cologne station

Thanks to funding from Smart City Cologne GO and the German Federal Ministry of Economics and Technology, the TX model from the manufacturer LEVC could be produced for the streets of Cologne. The special feature here is that these are electric vehicles that can be charged by an inductive charging process. The pilot project ended successfully and is still being continued today by the city of Cologne and Rheinenergie AG. In 2016, Cologne Public Transport launched a pilot project to convert its bus fleet to electric mobility. With the successful completion of the project, a large number of buses were converted to electric drive. KVB's goal is to convert the bus fleet completely to electric drive by 2030. Green electricity from Rheinenergie is used to charge the buses. In addition, with the help of subsidies from the state of North Rhine-Westphalia, a KVB depot was equipped with a carport that charges the e-buses. If the entire bus fleet is converted, up to 26,000 tons of CO2 can be saved annually. The GoFlux ride-sharing app was also funded by the Smart City Cologne GO program. The app was tested in the Widdersdorf district in order to raise residents' awareness of the environment and the effects of climate change, among other things. The company GoFlux claims to save around 550 tons of CO2 per month with 600,000 users throughout Germany. The latest Smart Mobility project of the city of Cologne is the so-called "Mobility Cockpit Cologne - innovative, integrative intelligent", MoCKiii for short. MoCKiii will use the collection of anonymized GPS data from vehicles and mobile communications data, among other things, to ensure that faster and better solutions can be found for traffic management in Cologne in the future. The first traffic management measures are scheduled to go into operation at the end of 2023. In order to improve the air quality in cities, the federal government has set up and funded the emergency program "Clean Air 2017-2020". In this context, the Office for Traffic Management of the City of Cologne has developed a Green City Master Plan, which is intended to reduce CO2 emissions and NOx through various measures. Before the start of the measures, many measuring points for monitoring air quality showed elevated values, which was another important factor in the creation of the Green City Master Plan. The Green City Master Plan addresses prioritized issues such as transportation, cycling, urban logistics and public transport connectivity. The city of Cologne received funding of 12 million euros from the federal government. As part of this work, targeted measures were presented that deal with mobility. One of these measures is to improve Cologne's cycling infrastructure because, as already mentioned, the trend towards cycling in Cologne is tending to increase. In addition to reducing NOx, another goal of this measure is to increase Cologne's bicycle mode share to 25%. If this were achieved, approximately 147 - 219 car kilometers and approximately 50 to 75 tons of NOx would be saved. The city of Cologne also wants to renovate and expand the existing bike paths. In addition, more cycle lanes and an improved Rhine crossing for cyclists are to be created. In total, the network of bicycle lanes has been expanded to 17.1 kilometers. The expansion of bike paths has also made bike sharing in Cologne more popular. In cooperation with the Cologne public transport company (KVB), there have been around 3,000 KVB rental bikes since June 2021. Around 3,000 rides are registered daily and in 2021 the number of rides amounted to around 1.5 million. This saves about 913,000 car kilometers and reduces NOx emissions to 0.31 tons. Since fall 2022, KVB's rental bike service has now been expanded to include cargo bikes. The pilot project will run for the next two years in three Cologne districts with a total of 15 cargo bikes. Another measure of the Green City Master Plan is so-called resident parking. Here, public parking spaces are converted into residents' parking spaces. In addition to the reduction of NOx, the search for parking spaces should be made easier for residents and the noise level in the city will also be reduced by the reduced search for parking spaces. By reducing the number of public parking spaces, commuters in particular are to be motivated to use other means of transport. In order to be able to assess the effects of this measure particularly well, a count of the number of parked cars was made both before and after the conversion of the parking spaces. Before the conversion, the occupancy rate was 110% due to many parking violations. After the conversion, the occupancy rate was 90%. Considering all residents' parking areas in Cologne per day, car kilometers are reduced by around 76,000. The reduced parking search traffic also accounts for around 11,000 car kilometers. Projected over the year, this means that around 23 million car kilometers are saved and NOx emissions are reduced by 8 tons. In order to make Cologne's suburban areas more commuter-friendly, the city of Cologne is working on a steady expansion of Park and Ride (P+R) parking spaces. This measure is not only intended to encourage commuters to travel into the city by public transport, but also to convince residents to leave their cars behind. This will not only reduce emissions and noise, but also the general traffic volume in the city center. Cologne currently has around 5,000 P+R parking spaces at a total of 26 locations, and further P+R facilities are being planned. Full use of these parking spaces could save around 3 tons of NOx per year. The Green City Master Plan also includes in its measures the planning of a transit ban on trucks weighing 7.5 tons or more in the city center. The no-trespass zone includes larger sections on both sides of the Rhine, as can be seen in Figure 12. If the measure is implemented, around 620,000 truck kilometers will be saved in the city center, and there will also be a reduction in NOx emissions of 0.9 tons of NOx per year. Another topic is currently going viral in the media. The topic of eFuels, so-called synthetic fuels. Especially until the final decision of the EU Commission to phase out combustion engines in 2035 on March 28, 2023, there was much discussion about whether an exception would be made for eFuels. In concrete terms, this means that combustion engines that can be fueled with eFuels may continue to be approved. With the decision of March 28, this exception has been confirmed, how exactly the regulation will look is still open. Research into synthetic fuels has been going on for some time. Porsche AG is a pioneer in this field among car manufacturers. In September 2021, Porsche's own eFuels production started in an industrial plant in Chile. After Porsche invested around 20 million euros in the construction, the German government supported the project with a further 8 million euros. The automaker's goal is to have produced around 550 million liters of eFuels by 2026. As with many newer technologies, there is potential for improvement in the production process for eFuels, as the energy input is high. When comparing the potential consumption of a passenger car fueled with eFuels, it can be extrapolated that a trip of 100 kilometers consumes approx. 104 kWh. With an electric car, consumption after 100 kilometers would be about 15 kWh. After 100 kilometers with a fuel cell vehicle, about 30 kWh are consumed. This shows that an electric car can be recharged up to eight times for the same range as the vehicle refueled with eFuels, using the same amount of energy. In addition, the comparison shows that eFuels are not very efficient so far, because on the one hand the energy input in the production process is very high and on the other hand the price per liter will be as high at the beginning, as experts assume. Other considerations by experts are that eFuels are a better alternative for ships, trucks and aircraft. Still, synthetic fuels are another climate-friendly option, along with electromobility and fuel cell vehicles. In addition, the stock of cars on the road could be CO2 climate neutral.

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