EUROPEAN MECHANICAL SCIENCE

Research Article

e-ISSN: 2587-1110

Investigation of alternative vehicle applications for reducing greenhouse gas emissions in urban public transport: The case of Adana province

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Abstract: Passenger cars, trucks, commercial airplanes, and railways all contribute to greenhouse gas emissions as part of the transportation sector. The usage of fossil fuels such as gasoline and diesel emits exhaust gases commonly referred to as greenhouse gases (GHGs) into the atmosphere. The buildup of these greenhouse gases in the atmosphere is responsible for global warming, a phenomenon that is becoming increasingly pronounced in today's climate. In response to the GHG problem, cities have started setting targets to reduce their emission values. Adana is one of the cities that has set reduction targets. In all of the studies forming the basis of this research, the potential for transitioning buses and minibuses used in public transportation in Adana to alternative vehicles is investigated, with a focus on reducing greenhouse gas emissions. This study includes a comparison between electric, compressed natural gas (CNG), hydrogen and conventional vehicles, considering various parameters such as fuel economy estimates, vehicle size, and emission calculations. The research delves into greenhouse gas emission calculations specific to the Adana province, along with potential alternative applications in public transportation. Within the province, the transportation sector accounts for 27% of the total city inventory's emissions. This study shows that converting the existing urban public transport fleet to alternative buses can lead an impressive reduction in greenhouse gas emissions as 81.93% with electric car, while hydrogen vehicles achieve a commendable 57.37% decrease. This underscores the substantial potential of electric and hydrogen-powered vehicles to lead to a significant reduction in transportation-related carbon emissions in the city. Consequently, the research places significant emphasis on addressing the transportation sector, which stands out as a primary contributor to emissions.

Keywords: Electric vehicle, CNG, hydrogen, diesel, greenhouse gas.

1. Introduction

Climate change refers to alterations in weather patterns, primarily stemming from the release of greenhouse gases by natural processes such as forest fires, earthquakes, oceanic activity, permanent ice melting, wetland dynamics, and volcanic eruptions [1], as well as human-driven actions, including energy production, industrial operations, and land use modifications [2,3]. Climate change stands as one of the foremost contemporary environmental challenges [4]. It poses several issues, including amplified global warming, heightened energy demands [5,6,7]. At the same time, cities play a pivotal role in worsening climate change, as urban activities act as substantial sources of greenhouse gas emissions. Estimates indicate that urban areas are responsible for approximately 75% of the world's CO_2 emissions, with transportation and buildings being the primary contributors to this substantial footprint. [8]. Simultaneously, cities serve as epicenters of creativity, innovation, and education, wielding the potential to drive substantial systemic changes across various critical environmental issues. With their local governments, cities are often the most capable entities to take proactive measures to address and resolve environmental challenges. Throughout history, municipalities have played pivotal roles in enhancing waste management, wastewater treatment, water resource management, public transportation, and urban land use through integrated urban planning strategies. In the present day, cities have taken on an increasingly central role in the realms of climate change mitigation and adaptation, the preservation and restoration of ecosystems, and the promotion of circular economies. Furthermore, the presence of easily accessible, high-quality green spaces within cities promotes physical and mental health, as well as social well-being [9].

Achieving triumph requires a synchronized strategy and execution at the global, regional, national, and local tiers. Hence, it is imperative to integrate cities as a fundamental component of the resolution to combat climate

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European Mechanical Science (2023), 7(4): 220-229
https://doi.org/10.26701/ems.1344141
Received: August 16, 2023 — Accepted: October 16, 2023

change. Numerous cities are already taking substantial actions by employing renewable energy sources, adopting cleaner production methods, and instituting regulations or incentives to cap industrial discharges. The mitigation of emissions will also lead to a decrease in localized pollution stemming from industries and transportation, thereby enhancing the quality of urban air and the well-being of urban inhabitants [8].

The Ministry of Trade in the Republic of Türkiye published Green Reconciliation Action Plan in July 2021. This action plan includes objectives, tactics, and educational initiatives aimed at various aspects, such as border carbon regulations, fostering a green and circular economy, promoting green finance, ensuring a clean, efficient, and secure energy supply, advancing sustainable agriculture, facilitating sustainable smart transportation, addressing climate change mitigation, diplomatic efforts, and aligning with the European Green Deal [10].

Some outputs of Türkiye's Green Deal Action Plan are as follows;

- ✓ *Carbon at the Border:* Harmonization of standards and certification activities within the scope of the EU's border carbon regulation,
- ✓ *Green and Circular Economy:* Preparation of needs and impact analysis reports on the basis of priority sectors,
- ✓ *Green Finance:* Preparation of draft legislation to develop the ecosystem that will enable the development of green finance in Türkiye,
- ✓ *Clean and Reliable Energy Supply:* 1 GW capacity increase per year until 2027 for new solar and wind power plant developments,
- ✓ *Sustainable and Smart Transportation:* Determining the requirements and standards needed for the installation, operation and equipment of electric vehicle charging stations,
- ✓ *Combating Climate Change:* Preparation of Türkiye Climate Change Mitigation Report [11].

In the sense of following these steps taken at the national level, also local mechanisms have started to demonstrate their desire to reduce urban emissions by setting targets for themselves. At this point; the Global Covenant of Mayors on Climate and Energy (GCoM) is a structure in which governing bodies at the local level set targets for future generations by making commitments on climate and energy actions. Cities that are party to the GCoM support a common vision for 2050. This vision involves uniting a global coalition of numerous cities and local governments, and it can be characterized as a long-term commitment to promote voluntary actions aimed at addressing climate change and establishing a resilient, low-emission society. The commitment of the cities participating in the GCoM is to take the necessary measures within the framework of a 30%-40% greenhouse gas reduction target by 2030 and to act supporting the adoption of a common approach to combating climate change[12]. Among the commitments of GCoM member cities are the following items;

- ✓ Preparation of a city-scale "Greenhouse Gas Emission Inventory" in accordance with the Sustainable Energy and Climate Action Plan (SECAP) guide,
- ✓ Assessment of climate risks and vulnerabilities,
- ✓ Setting ambitious, measurable and time-bound targets to reduce/prevent greenhouse gas emissions,
- ✓ Determination of ambitious climate adaptation vision and targets, based on numerical and scientific evidence as much as possible, in order to increase local resilience against climate change,
- ✓ Setting an ambitious and equitable target to improve access to safe, sustainable and affordable energy,
- ✓ Formulating formally endorsed strategies to tackle climate change mitigation/low emission development, enhance climate resilience and adaptation efforts, and ensure availability of sustainable energy [12].

Cities engaged in the GCoM have additionally embraced the SECAP, a strategic and policy dossier delineating the primary steps they intend to implement within a span of two years subsequent to the municipal council's resolution to translate their political pledges into tangible actions and initiatives.

1.1. Greenhouse Gas Emission in Transportation Sector

With the increasing world population over the years, people's need for transportation has also increased. Both passenger and freight transport play an important role. As a result of the need for transportation, the amount of CO_2 emissions has also increased. These emissions, which have increased over the years, will reach 12 Gt CO_2e/year in 2050 [13]. In 2021, carbon dioxide emissions from the transportation sector constituted 38% of energy-related emissions in the United States, making it the most significant contributor among all sectors of the economy [14].

In 2022, the recovery in both passenger and cargo transportation activities following the aftermath of the Covid-19 pandemic resulted in a 3% uptick in carbon dioxide (CO_2) emissions from the transport sector compared to the preceding year. Over the period spanning from 1990 to 2022, transport-related emissions exhibited an average annual growth rate of 1.7%, surpassing all other end-use sectors except for industry, which also experienced a similar growth rate of around 1.7%. In order to align with the Net Zero Emissions (NZE) target for 2050, it is imperative that CO_2 emissions stemming from the transportation sector witness an annual reduction of more than 3% by 2030. Achieving these reductions will necessitate the implementation of robust regulatory measures, fiscal incentives, and substantial investments in infrastructure to facilitate the operation of low- and zero-emission vehicles [15]. Achieving substantial cuts in CO_2 emissions within the transportation domain will prove to be a formidable challenge, given the deceleration in the pace of emission reduction. Present forecasts indicate a mere 22% reduction in transportation-related emissions by 2050, trailing significantly behind prevailing aspirations. With the introduction of road vehicles with carbon-free clean energy into our lives, greenhouse gas emissions can be reduced by 11.9% [16]. In 2019, transportation-based emissions in European countries remained a significant contributor to overall greenhouse gas emissions, with many nations implementing various measures to address and reduce their carbon footprint in this sector (Figure 1) [35]. Emissions stemming from the transportation sector involve a spectrum of greenhouse gases, encompassing carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO), and various hydrofluorocarbons (HFCs). The automotive industry is strongly committed to mitigating these emissions and enhancing fuel efficiency. On an average basis, a passenger car releases roughly 4.6 metric tons of carbon dioxide into the atmosphere each year. This amount may fluctuate based on factors like the vehicle's fuel type, fuel economy, and annual mileage [17]. However, it would be overly simplistic to anticipate that merely reducing fossil fuel consumption would constitute a globally effective strategy. The transportation sector dynamics are intricate and multifaceted, implying that achieving changes and advancements requires a multifaceted approach. Consequently, attaining anticipated efficiency gains in greenhouse gas reduction necessitates the implementation of multiple preventative measures.

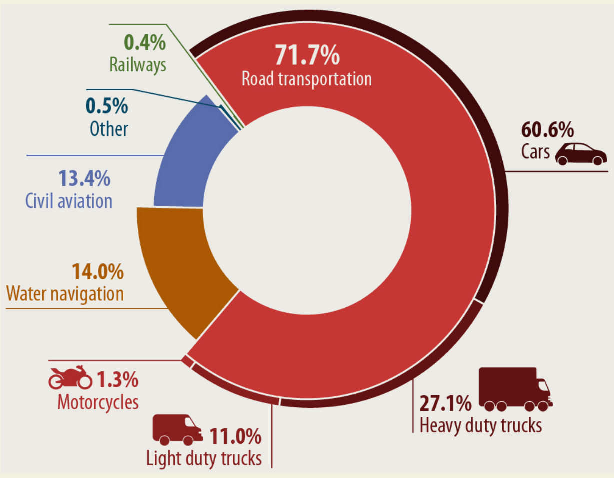

Figure 1. Transportation based emissions in the European countries, 2019 [35]

The literature presents seven key focal points for achieving sustainable transportation with reduced greenhouse gas emissions. These encompass the adoption of alternative fuels, the promotion of fuel-efficient vehicles, curbing vehicle usage, reducing transportation infrastructure footprints, fostering smart transportation systems, integrating transportation networks, and ultimately curtailing travel frequency [18]. It is widely recognized that the majority, if not all, of the environmental impacts and challenges arising from the transportation sector are a result of the excessive use of fossil fuels. [19]. Fuel consumption and associated greenhouse gas emissions within the transportation sector are categorized based on fuel type and transportation modes. Similarly, emissions within municipal operations are classified according to the fleet types employed by local governments for transportation activities, and these figures are integrated into emission inventory projections [20].

The United Nations Environment Program (UNEP) has introduced the eMob calculator, a tool facilitating the assessment of energy consumption, CO_2 emissions, air pollutants, and potential cost reductions linked to electric and low-emission buses (including Euro 6 and CNG buses). This initiative has showcased that the shift towards zero and low-emission vehicles, encompassing battery electric, hybrid, and compressed natural gas (CNG) buses, holds the potential to prevent roughly 1.4 billion tons of CO_2 emissions and approximately 30 million tons of particulate matter from 2020 to 2050. In 2020, the transportation sector was responsible for emitting 80.7 million tons of CO_2 equivalent, making up 15.4% of the total greenhouse gas emissions [21].

Electric vehicles (EVs) replace the traditional gasoline tank with a battery and substitute the internal combustion engine with an electric motor. Conversely, plug-in hybrid electric vehicles (PHEVs) integrate both gasoline and electric components, including a battery, an electric motor, a gasoline tank, and an internal combustion engine. PHEVs utilize both gasoline and electricity as sources of energy.

The shift towards electric vehicles (EVs) arose from concerns about depleting crude oil reserves and a growing societal awareness of the environmental impacts linked to fossil fuel combustion. The escalating energy demand resulting from industrial growth in emerging and established nations further accentuates these countries' reliance on imported oil. Consequently, nations dependent on foreign oil allocation must earmark significant portions of their domestic revenues for petroleum imports [22]. Figure 2 displays the emissions for different vehicle categories, while Figure 3 illustrates hydrogen's exceptional energy density in comparison to alternative technologies.

The emerging advancements in the fuels industry are positioning hydrogen and CNG as highly suitable options for sizeable vehicles such as buses. These vehicles are gaining increasing popularity among the general populace, thanks to their substantial potential as an energy source with minimal harm to the environment. These gases are regarded as eco-friendly and environmentally conscious fuels, primarily derived from sustainable sources. This trend is opening up fresh possibilities within the fuel market [37,38].

https://doi.org/10.26701/ems.1344141

Highways are the most frequently used mode of transportation. Therefore, the characteristics of the fuel burned play a significant role in determining emission values. CO_2 emissions per liter of used fuels vary depending on the fuel type. CO_2 emissions corresponding to each fuel type are provided in Table 1.

Table 1. Carbon dioxide emissions due to fuel consumption per liter fuel type CO_2 emissions [24]

Fuel Type	CO_2 Emission (g of CO_2 per liter)
Diesel	2,700
Gasoline	2,500
LPG	1,600

In Türkiye, the greenhouse gas inventory findings indicated that in 2021, the total greenhouse gas (GHG) emissions, measured in terms of CO_2 equivalent (eq.), increased by 7.7% compared to the preceding year, reaching a total of 564.4 million tonnes (Mt). On a per capita basis, the total GHG emissions were 6.3 tonnes of CO_2 eq. in 2020 and 6.7 tonnes of CO_2 eq. in 2021. The share of transport-related emissions in total greenhouse gas emissions was 15.3% in 2019. According to Turkish Statistical Institute's (TURKSTAT) greenhouse gas emission inventory data for 2020; 94.9% of the CO_2 emissions originating from transportation originate from the road, 2.7% from the airway, 1.6% from the seaway, 0.4% from the railway and 0.4% from other modes of transport [25].

As part of the Sustainable Energy Action Plan (SEAP), a comprehensive analysis of Antalya's 2019 emissions was determined. Including industrial contributions, reveals that the total energy consumption in the province amounted to 28,623,531 MWh, resulting in greenhouse gas emissions totaling 10,683,551 tCO_2e. Notably, the transportation sector accounts for 30.2% of these emissions [26]. As detailed in the Izmir SECAP report for 2018, the current greenhouse gas emissions in the transportation sector constitute 23.1% of the municipality's total emissions, equivalent to 5,780,293 tCO_2e. The primary culprits within the transportation sector are private vehicles, including cars, minibuses, buses,

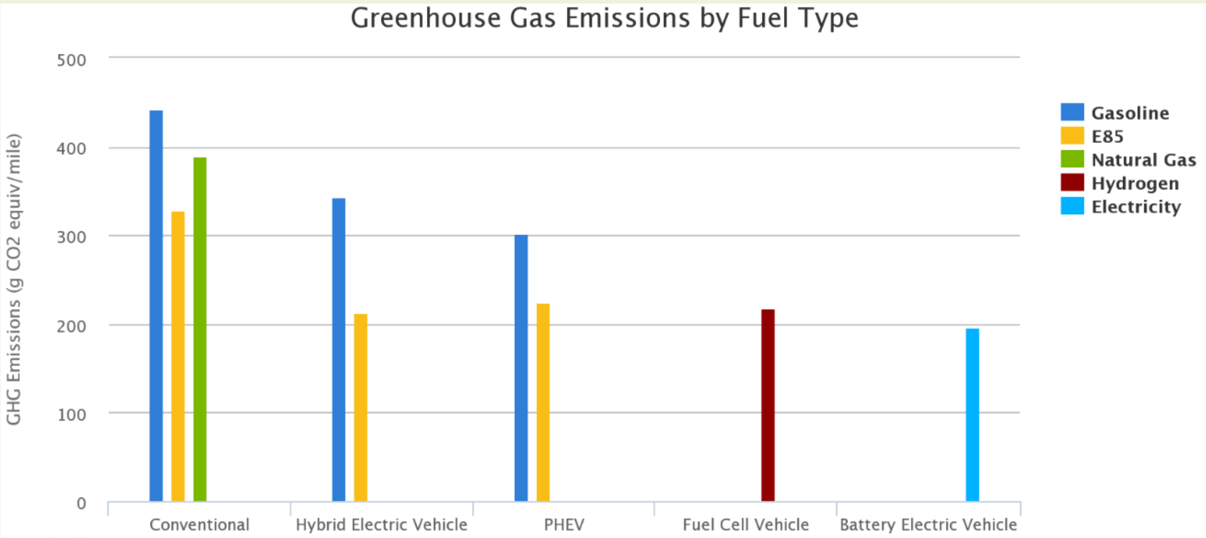

Figure 2. A comparison among different models of vehicles in terms of greenhouse gas emissions [23]

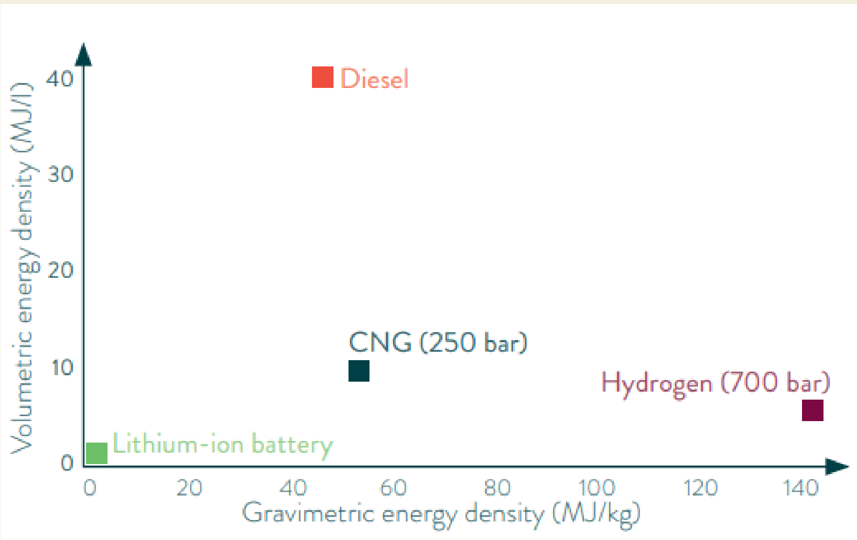

Figure 3. Hydrogen's high energy density compared to other technologies [36]

trucks, pick-up trucks, and motorcycles, accounting for 19.9% of these emissions. Notably, a significant portion of these private vehicles are quite old, with an average age exceeding 13 years, and they predominantly rely on fossil fuels for power. To be precise, approximately 46% of these vehicles use diesel fuel, contributing not only to greenhouse gas emissions but also to the release of other harmful gases, thereby negatively impacting air quality [27]. In contrast, the greenhouse gas emissions in Ankara, calculated using the GPC BASIC approach for 2019, amount to 22,884,636 tCO_2e (the breakdown of these emissions, with 72% stemming from 'Scope 1 - Direct Emissions' and 28% from 'Scope 2 - Indirect Emissions.) Stationary energy sources contribute the highest proportion at 39%, followed by transportation at 28%, and waste management at 2% [28]. In accordance with the GPC BASIC Standards for Stationary Energy, Transportation, and Waste sectors, the total greenhouse gas emissions at Istanbul for 2019, amount to 50,888,653 tCO_2e. Of this total, the sector with the most substantial share is stationary energy, accounting for 63%, followed by transportation at 28%, and waste at 9% [29]. The greenhouse gas emission total for the province of Adana in 2020 was determined to be 9.7 metric tons of CO_2 equivalent (tCO_2e), with a per capita carbon footprint calculated at 4.3 tCO_2e. [20].

1.2. SECAP studies in Adana Province

The Mediterranean Region, where Adana City is located, faces significant climate change impacts, including rising temperatures, droughts, reduced water availability, and extreme weather events. Adana, like many other provinces, is already experiencing these effects. In 2021, the Adana Metropolitan Municipality (AMM) joined the Global Covenant of Mayors (GCoM) with a goal to reduce emissions by 40% by 2030 compared to 2020 levels. AMM conducted a thorough greenhouse gas emissions assessment and identified strategies for achieving this reduction. They also conducted a Risk and Vulnerability Analysis to pinpoint climate-related hazards and vulnerabilities in the city, resulting in an adaptation strategy and measures to address these risks. Adana faces challenges like prolonged heatwaves, increased droughts, urban flooding, and forest fires. Key priorities include expanding carbon sink zones, improving waste management, enhancing transportation, and promoting renewable energy. Rainwater harvesting and wastewater recovery are also essential parts of AMM's agenda.[30].

Adana's Sustainable Energy and Climate Action Plan (SECAP) envisions the city becoming a low-carbon urban hub, integrating measures to meet reduction targets with existing strategies. The goal is an energy-efficient city with reliable access to sustainable energy sources, enhancing resilience against climate change. The SECAP is a strategic blueprint for Adana, outlining both mitigation and adaptation actions, setting timelines, and responsibilities. It focuses on boosting energy efficiency and renewable energy adoption to reduce urban emissions. The plan aligns with existing frameworks and governance structures and includes recommendations for their strengthening. It's a flexible document meant to adapt to evolving circumstances and insights, ensuring ongoing climate action. Adaptation measures consider current conditions, educational insights, references, and extreme weather events. [20].

2. Methodology

The approach used in this study for reporting greenhouse gas emissions adheres to the Global Protocol on Community Scale Greenhouse Gas Emissions Inventories (GPC), a standard endorsed by the Global Covenant of Mayors for Climate and Energy (GCoM). This protocol is based on the 2006 Guidelines from the Intergovernmental Panel on Climate Change (IPCC) for National Greenhouse Gas Inventories [12]. In the context of Adana City, projections for greenhouse gas emissions in 2030 were calculated by using the greenhouse gas emission inventory data from the baseline year of 2020. This inventory encompasses the assessment of carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (N_2O) as the primary greenhouse gases of interest. These gases are particularly significant in terms of emissions arising from energy consumption within the city's boundaries, as well as activities extending beyond energy use. To clarify, CO_2 constitutes the majority of emissions, while CH_4 and N_2O originate from different sources. In the calculations, we have included the carbon dioxide equivalent (tCO_2e) of emissions from CH_4 and N_2O, utilizing the global warming potentials specified in the IPCC 5th Assessment Report (AR5) [31].

In this study, we also incorporated the Kaya Identity (KI) model in the computation of greenhouse gas emission projections. The KI model serves as a crucial foundation for estimating greenhouse gas emissions, identifying emission-intensive areas, and formulating relevant policies. The preeminent method employed for estimating greenhouse gas emissions is the Kaya Identity equation, originally formulated by the Japanese energy economist Yoichi Kaya [32]. The Kaya Identity, utilized for forecasting greenhouse gas emissions by both the Intergovernmental Panel on Climate Change (IPCC) and the C40 Cities Climate Leadership Group, recognizes that greenhouse gas emissions are directly influenced by four primary factors. These factors include:

- ✓ Population
- ✓ Economic Output (Gross Domestic Product)
- ✓ Energy Efficiency of the Economy
- ✓ Carbon Efficiency of the Economy

At the Kaya Identity equation;

CO_2 emissions are defined as; Population × (Gross Domestic Product/Population) × (Energy/Gross Domestic Product) × (CO_2/Energy) and constitute an equality in terms of population, economy, politics, energy [33]. This equivalence provides a new perspective on how each country emits greenhouse gases by including carbon emission factors within itself. The population projections for Türkiye and Adana for the period spanning from 2020 to 2030 were integrated into the Kaya Identity Model. These projections were sourced from official references provided by TURKSTAT, including TURKSTAT's Population Data for Provinces from 2018 to 2025, Türkiye's Population Projections from 2018 to 2080, Results derived from the Address-Based Population Registration System spanning from 2007 to 2021 [34] In addition, for the population projection after 2025, the population growth rates predicted by TURKSTAT for the years 2018-2025 for Türkiye and Adana Province, and the population growth rate predicted for Türkiye until 2080, were taken into account. The difference between the population growth rates of Türkiye and Adana Province 2018-2025 has been used for the post-2025 population projection of Adana Province.

GDP per capita is another critical factor considered in greenhouse gas emission projections. The GDP values utilized in these calculations were obtained from the "Gross Domestic Product on Province Basis, 2004-2020" report published by TURKSTAT [34]. Between 2004 and 2020, the per capita GDP growth in Adana in US$ units was calculated as 1.80% per year on average. In the emission projections, it is assumed that the GDP per capita will experience an annual growth rate of 1.80% for the period from 2020 to 2030.

In the context of carbon intensity and energy intensity for Türkiye between 2010 and 2016, it is assumed that there will be an annual decrease of 2.6% in carbon intensity and 1.98% in energy intensity from 2020 to 2030. This assumption forms the basis for calculating annual carbon intensity and energy intensity values, which are subsequently used in greenhouse gas emission projections for Adana Province.

To calculate greenhouse gas emissions for a specific year in a particular region according to the Kaya Identity, the following formula is employed:

CO_2 equivalent (GHG) emissions = Population × (GDP/Population) × (Energy/GDP) × (CO_2/Energy)

The "CO_2/Energy" factor in the formula can be calculated as follows:

CO_2/Energy = (Carbon Intensity of Economy/Energy Intensity of Economy)

Based on the provided values for carbon intensity and energy intensity, the "CO_2/Energy" factor has been calculated as "0.994." This factor is crucial for estimating greenhouse gas emissions in Adana Province for each year within the 2020-2030 timeframe.

The calculation method for estimating greenhouse gas emissions for the year 2020 and subsequent years in Adana Province, based on the Kaya Identity formula, is described as follows:

2020 CO_2equivalent (GHG) emissions = [2019 CO_2equivalent (GHG) emissions × (2020 Adana Province Population/2019 Adana Province Population) × (2020 GDP Per Capita/ 2019 GDP Per Capita)] × (CO_2/Energy)

This formula allows for the projection of greenhouse gas emissions for 2020 and beyond by considering population growth, changes in GDP per capita, and the CO_2/Energy factor, as described above.

In the context of efforts to address climate change, an assessment of Adana City's transportation sector was carried out by conducting a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. To assess the Adana City transportation sector's role in addressing climate change, information from the Sustainable Energy and Climate Action Plan, a collaborative effort among various institutions, served as the primary data source [20]. These data resources encompassed details regarding Adana's transportation infrastructure, encompassing vehicle categories, traffic patterns, and utilization statistics. Environmental impact evaluations and climate change assessments were referenced to ascertain the sector's influence on greenhouse gas emissions and air quality, assisting in the identification of environmental strengths and weaknesses. Valuable insights into the public's perception of the transportation system's effectiveness were gleaned from public opinion surveys. The analysis also delved into ongoing and prospective transportation projects, governmental policies, and regulatory frameworks to pinpoint opportunities and threats, with a particular emphasis on reducing carbon emissions. Additionally, an examination of economic and financial data, technological advancements, and the resilience of transportation infrastructure to climate-related risks were integral components of the study. This analysis provided a

Table 2. The current data on Adana City transportation in the year 2020 [20]

Data Name	Value	Unit
Number of Diesel Buses (Public Transport)	324	units
Number of Diesel Buses (Private Transport)	419	units
Distance Covered per Bus (Public Transport)	71,603	km/year
Distance Covered per Bus (Private Transport)	59,236	km/year
Distance per Bus (Average)	64,629	km/year
Diesel Bus Fuel Consumption (Public Transport)	0.48	lt/km
Diesel Bus Fuel Consumption (Private Transport)	0.35	lt/km
Diesel Bus Consumption (Average)	0,41	lt/km
Average Electric Vehicle Electricity Consumption	0.85	kWh/km
Number of Diesel Bus Passengers (Public Transport)	52,288	passengers/year
Number of Diesel Bus Passengers (Private Transport)	64,629	passengers/year

methodical framework for evaluating the present state and potential enhancements within Adana's transportation sector concerning climate change mitigation, offering a comprehensive viewpoint on the determinants of the sector's success or challenges. In this research, it was focused on public and private transportation vehicles, which hold a significant position in urban emission sources. Public buses, as mentioned Table 2., pertain to the municipal-owned vehicles, while private buses refer to smaller-sized vehicles commonly recognized as minibuses. All these vehicles utilize diesel fuel, and our study aims to explore the potential impact of alternative fuel system conversions on emission levels. The current data on Adana City transportation in the year 2020 are in Table 2. below;

3. Results

3.1. Adana City Transportation Sector SWOT Analysis

The results of the SWOT analysis of transportation sector are given below;

Strengths:

- ✓ Pursuing the strategic objective of efficient transportation service management, aiming to deliver economical, secure, and convenient services across all corners of the city,
- ✓ Ongoing development of the Transportation Master Plan study,
- ✓ Enlarging the rail system network to enhance connectivity,
- ✓ Launching an extensive citywide bicycle path project aimed at promoting active transportation throughout the urban area,
- ✓ Introducing intelligent transportation systems to enhance transportation efficiency and effectiveness,
- ✓ Undertaking citywide road and infrastructure maintenance and restoration projects to ensure their long-term sustainability.

Weaknesses:

- ✓ Limited integration among diverse transportation modes,
- ✓ Urban design prioritizing motor vehicle usage,
- ✓ Insufficient awareness regarding active transportation.

Opportunities:

- ✓ The potential to curtail private car reliance through mobility management and optimization of the road network,
- ✓ Opportunities for adopting electric vehicles as a part of the transportation system,
- ✓ Possibilities to encourage stakeholder engagement in the planning, implementation, and oversight of transportation initiatives.

Threats:

- ✓ Difficulties in organizing the road network,
- ✓ Public transportation and practices that support active transportation are not adopted by the citizens.

To compare the greenhouse gas (GHG) emissions of diesel buses and electric vehicles (EVs), 2.602 kg CO_2e per liter fuel consumption data for diesel buses and the electricity consumption data for EVs were used. The GHG emissions from electric vehicles depend on the carbon intensity of the electricity generation source. This is an estimate and may vary based on the specific geographical region and the percentage of renewable energy sources integrated into the grid.

Emissions from hydrogen vary significantly depending on the production method employed. There are three common types of hydrogen: gray, blue, and green hydrogen. The carbon intensity for hydrogen production ranges from 850 to 71 g CO_2/km [39]. For this study; the average of these was determined as 0,460 kg CO_2/km.

The carbon dioxide equivalent (CO_2e) emissions for CNG can vary depending on various factors such as the source of the natural gas and the efficiency of the CNG production and distribution process. On average, CNG is considered to have lower CO_2e emissions compared to traditional gasoline or diesel fuels. Performance value for CNG was given 0.833 kg CO_2/km. at the literature [40].

3.2. GHG Projections and Reduction Results

Within the scope of this study, greenhouse gas emission projections for the 2020-2030 period were prepared

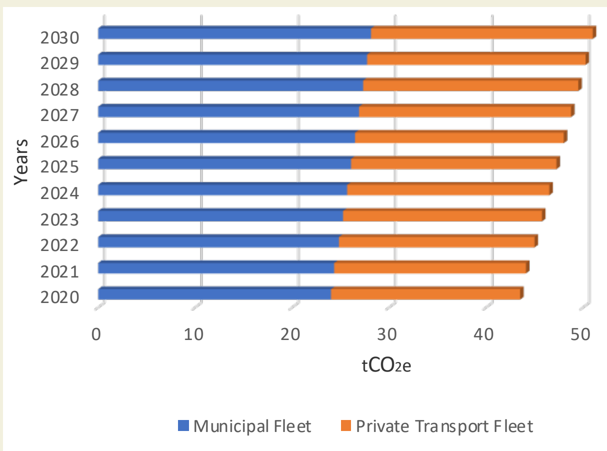

Figure 3. Amount of greenhouse gas in case of without mitigation studies (2020-2030 term)

based on the 2020 greenhouse gas emission inventory has been prepared. It was prepared with the KI methodology. The greenhouse gas emission projections for Adana City for the period of 2020- 2030, which have been developed within this framework, are elaborated in Figure 3 below.

The GHG emissions for both different vehicles are given below in Table 3.

Table 3. GHG Emissions for different vehicle types

Vehicle Type	GHG Emissions ($kg\ CO_2e/km$)	Bus Fleet (743 bus) ($kg\ CO_2e/km$)
Public-Private Transport Diesel Bus (average)	1.079	801.697
Electric Vehicle	0.195	144.885
Hydrogen	0.460	341.78
CNG	0.833	618.919

When comparing greenhouse gas (GHG) emissions of different vehicle types to the average diesel bus emissions, several key insights emerge. In contrast, electric vehicles demonstrate a remarkable environmental advantage, showcasing a significant 81.93% decrease in GHG emissions. Hydrogen-powered vehicles also offer a notable reduction of approximately 57.37% compared to diesel buses. Compressed Natural Gas (CNG) vehicles provide a moderate decrease of around 22.77%. These percentages underscore the potential for electric and hydrogen vehicles to substantially contribute to lowering carbon emissions in the transportation sector, while CNG serves as an intermediate step toward cleaner mobility solutions.

Even with the revised diesel emissions factor, it is clear that electric vehicles maintain a notably lower greenhouse gas emissions profile when compared to both public and private diesel buses in the transportation sector. The shift toward electric vehicles still presents substantial environmental advantages in terms of mitigating carbon emissions.

Based on the results of the greenhouse gas transportation emission inventory for the 2020 base year in Adana City, it was determined that emissions accounted for 27% of the total. Originating from public transportation and municipal fleet vehicles was determined as 19,500 tCO_2e and 24.003 tCO_2e, respectively. In addition, the greenhouse gas emission projections until 2030 are given below; if a greenhouse gas reduction study is not carried out, it has been calculated that the greenhouse gas emission value from public transportation and municipal fleet vehicles in 2030 could be 22,859 tCO_2e and 28.137 tCO_2e respectively.

To address this challenge and reduce GHG emissions, transitioning to electric bus alternatives is a viable solution. Electric buses produce significantly lower or zero tailpipe emissions when compared to their internal combustion engine counterparts. Electric buses operate without burning fossil fuels, leading to lower or zero emissions of pollutants and GHGs during operation. This directly contributes to lowering the transportation sector's carbon footprint. Electric buses produce fewer pollutants like nitrogen oxides and particulate matter, leading to improved air quality. This has positive implications for public health and environmental well-being. In summary, the data underscores the importance of addressing emissions from diesel buses, both in the public and private transport sectors. The transition to electric buses not only offers a promising solution for reducing carbon emissions but also has the potential to enhance the sustainability and environmental quality of urban transportation. Additionally, the substantial passenger capacity of these buses highlights their critical role in providing mobility services to the community, making the move toward electric buses even more impactful from both environmental and societal perspectives.

4. Conclusions

The engineering and technical aspects of electric buses represent a pivotal and transformative force in the ongoing efforts to significantly reduce greenhouse gas (GHG) emissions. Their remarkable efficiency serves as a beacon of hope in the fight against climate change, delivering a significant 81.5% reduction in emissions when contrasted with the average diesel-powered bus. This noteworthy reduction not only lessens the burden on our environment but also results in tangible benefits for the air quality in our cities, as electric buses produce zero tailpipe pollutants. However, the genuine environmental impact of electric buses becomes even more profound when taking into account the potential for seamless integration with renewable energy sources in their charging infrastructure. When these buses are powered by clean energy grids, they can achieve a staggering 100% reduction in emissions, making them a shining example of sustainable transportation.

One of the key enablers of the electric bus revolution is the continuous advancement in battery technology. These innovations have significantly extended the operational range of electric buses while enhancing their overall efficiency. As a result, electric buses have become a highly viable and environmentally friendly choice for public transportation, offering a sustainable alternative to traditional fossil fuel-powered vehicles. It's important to note that the transition to electric vehicles, including buses, is not confined to the public transportation sector alone. Efforts to combat climate change extend to both private vehicles and public transportation, with a primary emphasis on shifting from fossil fuel-powered vehicles to low-emission alternatives, such as electric vehicles. In this context, electric buses play a crucial role in setting an example for the broader transportation industry. To quantify the significant advantages of embracing electric buses, our analysis relied on both primary data collected from authoritative sources such as AMM and secondary data sourced from reputable national and international organizations. This approach allowed us to provide robust estimates of the emissions reductions achievable through the widespread adoption of electric buses. In comparing various vehicle types to the average diesel bus emissions, electric vehicles demonstrate a significant 81.93% reduction in GHG emissions, while hydrogen vehicles achieve a notable 57.37% decrease. These findings highlight the substantial potential of electric and hydrogen-powered vehicles in reducing carbon emissions in transportation. This progressive trajectory not only promises to revolutionize public transportation systems but also to establish a more sustainable and greener transportation landscape that surpasses the current scenario. By doing so, it contributes to the well-being of our planet and ensures a healthier environment for future generations. By embracing electric buses and the associated advancements in clean energy, we take a significant step forward in building a more sustainable future for all.

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