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Article

# Renewable energy in transportation: economic and environmental trade-offs

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**ABSTRACT**

This paper explores the benefits and challenges of transitioning from fossil-fueled vehicles to electric vehicles in Iran, with a focus on economic and environmental analysis. To this end, three different scenarios were considered to evaluate the impacts of this transition: the baseline system (fossil-fueled vehicles only), electric vehicles powered by fossil-based electricity, and electric vehicles powered by renewable energy. Each scenario was analyzed using various criteria, including fuel and maintenance costs, greenhouse gas emissions, required infrastructure investments, and return on investment. The results reveal that in the baseline scenario, annual $CO_2$ emissions of 73.25 million tons and total annual costs of $1.92 billion are among the main challenges. In the second scenario, with a 50% penetration of electric vehicles powered by fossil-based electricity, $CO_2$ emissions are reduced by 36.76 million tons, and the return on investment is achieved within five years. In the third scenario, assuming renewable energy sources supply electricity and a 70% penetration of electric vehicles, $CO_2$ emissions are reduced by 114.49 million tons, and a return on investment of 32.6% is achieved. These findings underscore the importance of integrating electric vehicles with renewable energy to achieve economic and environmental sustainability. The study highlights the critical need for developing renewable energy infrastructure and implementing appropriate policies to accelerate the transition to electric vehicles.

## 1. Introduction

Due to global concerns such as climate change and environmental pollution, various countries are moving toward sustainable and green economic development [1, 2]. Among the critical sectors underpinning any country's economic development is the transportation sector. This highlights the importance of focusing on transportation to achieve sustainable and green economic development. According to data published by the IEA in 2023, global $CO_2$ emissions exceeded 30 billion tons in 2021, serving as a serious warning to the international community. The transportation sector is responsible for 25% of these emissions and accounts for 55% of global oil consumption [3-6]. In recent years, governments worldwide have prioritized replacing fossil fuels with renewable energy sources in the transportation sector to achieve sustainable and green economic growth [1, 2]. One of the key strategies to reduce greenhouse gas emissions in transportation is the adoption of EVs, provided that their electricity is generated using renewable energy sources such as wind and solar power. According to statistics from the IEA, the sales of electric vehicles across various regions from 2012 to 2024, illustrated in Figure 1, demonstrate a growing global inclination toward EV adoption, especially in developed countries [7]. So far, extensive research has been conducted on the use of electric vehicles and their role in addressing environmental, economic, and energy network challenges across different countries, some of which are discussed below. Li et al. [8] investigated various scenarios for the deployment of electric vehicles in their country, focusing on their impact on the energy mix, economic outcomes, and environmental consequences, considering expected developments by 2030. Li et al. [8] also aimed to develop the electric vehicle market through improving charging strategies and power system design in China.

**Abbreviations**

| | |
|---|---|
| BEVs | Battery Electric Vehicles |
| CPVT | Concentrated Photovoltaic-Thermal |
| EVs | Electric Vehicles |
| FCEVs | Fuel Cell Electric Vehicles |
| HO | Highway Operator |
| IEA | International Energy Agency |
| ILUC | Indirect Land Use Change |
| MESV | Mobile Energy Storage Vehicle |
| MILP | Mixed Integer Linear Programming |
| RES | Renewable Energy Systems |

Their findings indicated that, from an environmental perspective, the adoption of electric vehicles in China does not effectively reduce $CO_2$ emissions. This is primarily because the electricity required for these vehicles is generated using coal rather than renewable energy sources. As a result, the electrification of vehicles merely shifts the energy mix rather than improving $CO_2$ emissions, with coal replacing gasoline as the energy source. Economically, electric vehicles outperform gasoline vehicles in terms of average fueling costs. The study suggested that, from both environmental and economic perspectives, it would be more beneficial for electric vehicles to rely on renewable energy or even natural gas for electricity generation. Additionally, establishing $CO_2$ emission regulations for electricity production and transmission could significantly contribute to the development of electric vehicles. In another study conducted by García-Olivares et al [9], a 100% renewable energy system for the transportation sector was proposed. This study examined existing and emerging technologies for replacing fossil fuels in transportation and estimated the energy requirements and costs associated with transitioning to a fully renewable transportation system. The results revealed that such a system could reduce global transportation energy consumption by 18%, with a 69% reduction expected in road transportation. However, aviation and maritime transportation are projected to see increases of 149% and 163%, respectively.

The study concluded that transitioning to a 100% renewable transportation system is feasible but would require careful management of natural resources and overcoming challenges related to material and energy consumption across various sectors. Another study by Ding et al [1] focused on promoting sustainable and green economic development. Using a two-stage least squares regression approach, this research analyzed the impact of renewable energy adoption on achieving sustainability in China's transportation sector. The results indicated that renewable energy utilization and investments in green financing are two key factors for establishing an environmentally friendly transportation system. Furthermore, these factors play a significant role in reducing carbon emissions and fostering green economic growth. The research by Zahoor et al. [10] focused on the development of electric vehicles and their role in reducing carbon emissions. It examined technologies and policies that could facilitate the adoption of electric vehicles in China. The findings revealed that government policies, such as tax exemptions, advancements in innovative technologies, expansion of charging infrastructure, and easing traffic restrictions, could significantly boost the adoption of electric vehicles and reduce $CO_2$ emissions. The analysis showed that the share of renewable energy in China's electricity mix could increase from 42% in 2030 to 93% by 2060, while the reliance on fossil fuels could decrease from 55% to 4%. In another study conducted by Taghizad et al. [5], the focus was on the role of electric vehicle charging stations and load distribution management within power grids to support electric vehicle development. The researchers emphasized that establishing charging stations powered by renewable energy sources could further enhance the adoption of electric vehicles and reduce environmental pollution. The study analyzed global standards for EV charging, different types of EVs, and converter architectures (AC-DC and DC-DC) to address challenges related to peak demand and ensure the efficiency of charging infrastructure. The results indicated that smart and controlled charging strategies could alleviate grid pressures, enhance the integration of renewable energy sources, and optimize the design and implementation of EV charging infrastructure.

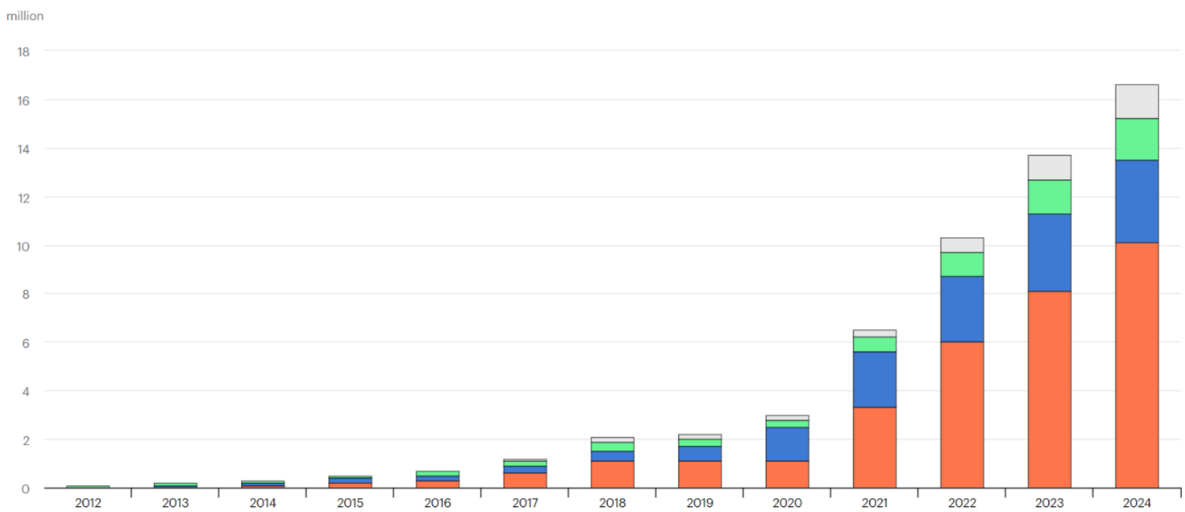


**Figure1.** The number of sales of electric cars in different regions of the world [7]

Table 1 (Appendix I) presents additional research that reviews the articles in terms of content, furthering our understanding of previous research.

Considering the review of previous studies, although various research efforts have sought to highlight the role of renewable energy in the transportation sector by introducing diverse technologies and assessing the environmental benefits of these resources, as well as analyzing the impact of incorporating renewable energy into transportation from the perspective of national energy networks, a comprehensive study addressing the balance and trade-offs between the economic and environmental advantages and disadvantages of using such energy sources remains absent. The significance of this research lies in the fact that merely examining environmental and technical aspects is insufficient for the development of renewable energy in the transportation sector. A thorough and simultaneous evaluation of economic costs and benefits alongside environmental aspects is essential. Consequently, this study aims to achieve a deeper understanding of how to create a relative balance between environmental and economic factors in a manner that fosters the sustainable development of renewable energy in transportation. It can serve as a foundation for policymaking and the sustainable development of renewable energy in this sector. This paper seeks to provide a comprehensive analysis of the economic and environmental impacts of utilizing renewable energy in transportation, focusing on how to balance economic benefits, such as reducing operational costs and improving energy efficiency, with environmental advantages, such as reducing emissions and preserving ecosystem sustainability. Through a quantitative and qualitative analysis of these aspects, the study aims to identify the opportunities and challenges of sustainable renewable energy development in transportation and offer policy recommendations to optimize this balance. The ultimate goal of this research is to propose an approach that minimizes the negative economic and environmental impacts while paving the way for more informed and effective decision-making toward sustainable transportation development.

## 2. Methodology

This section explains the research process, various scenarios, and data used in the economic and environmental analysis of transitioning from fossil-fuel vehicles to EVs in Iran. The statistics and figures employed in this research, which serve as the foundation for calculations in subsequent sections, are based on the most recent and reliable data from the Iranian Energy Balance Sheet (2021). These data form the primary basis for all calculations and analyses. The main objective of this research is to analyze the economic and environmental advantages and disadvantages of using electric vehicles powered by various energy sources.

### 2.1 Research objectives

The primary goal of this paper is to examine and analyze the economic and environmental impacts of transitioning from fossil-fuel vehicles to electric vehicles in Iran. The specific objectives of this research are:

- To compare the economic and environmental costs of using fossil-fuel vehicles versus electric vehicles.
- To analyze various energy supply scenarios for electric vehicles and their impact on reducing $CO_2$ emissions.
- To evaluate the environmental and economic benefits of using electric vehicles powered by renewable energy sources.

### 2.2 Research methodology and models

This research is based on three main scenarios and three sub-scenarios, which are explained in detail below:

- Scenario 1 (Baseline System): In this scenario, all vehicles are fossil-fuel-based, and no electric vehicles are used. This scenario serves as the baseline for comparison with other scenarios.
- Scenario 2 (Electric Vehicles with Fossil-Fuel Electricity): In this scenario, it is assumed that electric vehicles are solely powered by fossil-fuel energy sources. This scenario is analyzed under the following three conditions:
  - Case 1 (30%): 30% of vehicles are electric.
  - Case 2 (50%): 50% of vehicles are electric.
  - Case 3 (70%): 70% of vehicles are electric.
- Scenario 3 (Electric Vehicles with Renewable Electricity):

In this scenario, it is assumed that electric vehicles are powered solely by renewable energy sources (e.g., solar, wind, etc.). This scenario is also analyzed under the following three conditions:

- Case 1 (30%): 30% of vehicles are electric.
- Case 2 (50%): 50% of vehicles are electric.
- Case 3 (70%): 70% of vehicles are electric.

Table 2 contains the economic and environmental data used for analyzing the transition from fossil-fuel vehicles to electric vehicles in Iran. All statistics and figures in this study are extracted from the Iranian Energy Balance Sheet (2021) and are considered the most up-to-date and reliable data available in this field. To determine the required investment for charging stations, Equation (1) will be used.

$$\text{Total Investment for Charging Stations} = \text{Number of Stations} \times \text{Cost per Charging Station} \quad (1)$$

In Equation (1), the number of charging stations will be calculated using Equation (2).

$$\frac{N_{car}}{N_{day} \times N_{cs}} = N_s \quad (2)$$

In this context, $N_{car}$ represents the number of electric vehicles, $N_{day}$ is the number of operational days for a station in a year, $N_{cs}$ refers to the daily capacity of a station for charging vehicles, and $N_s$ represents the number of charging stations. The number of operational days will be considered as 365 days, and the daily capacity of the station will be set to 20 vehicles in this study.

Additionally, the cost for equipment, installation, and necessary infrastructure for one charging station in Iran is approximately 875 USD. The internal rate of return is calculated using the cash flow of the project over time, as expressed in Equation (3).

$$\sum_{t=0}^{n} \frac{(NCF)_t}{(1+\mathrm{IRR})^t} = 0 = NPV \quad (3)$$

NCF refers to the net cash flow, which is obtained according to Equation (4).

$$NCF = \text{Annual Income} - \text{Annual Operational Costs} \quad (4)$$

**Table 2.** Comparison of economic and environmental data of fossil and electric vehicles

| Item | Details |
|---|---|
| Total number of fossil-fuel vehicles | 41 million units |
| Average fuel consumption of fossil-fuel vehicles | 6.9 liters per 100 kilometers |
| Average distance traveled per vehicle per month | 400 kilometers |
| Annual gasoline consumption | 31,851.4 million liters |
| Annual LPG consumption | 2,545 million cubic meters |
| Annual crude oil equivalent natural gas consumption | 54.6 million barrels of oil equivalent |
| Cost per liter of gasoline | 2.8 cents |
| Fuel cost per kilometer for fossil-fuel vehicles | 0.18 cents |
| Charging cost per kilometer for electric vehicles | 0.09 cents |
| Average purchase price of fossil-fuel vehicles | \$437.50 |
| Average purchase price of electric vehicles | \$4,375 |
| Annual maintenance cost of fossil-fuel vehicles | \$25 |
| Annual maintenance cost of electric vehicles | 33% less than fossil-fuel vehicles (\$16.75) |
| Electricity cost for electric vehicles | 0.68 cents per kilowatt-hour |
| The average battery capacity of electric vehicles | 50 kilowatt-hours |
| Range of electric vehicles on a single charge | 400 kilometers |
| $CO_2$ emissions from fossil-fuel vehicles | 2.3 kilograms of $CO_2$ per liter of gasoline |
| $CO_2$ emissions from electric vehicles using fossil-fuel electricity | 0.6 kilograms of $CO_2$ per kilowatt-hour |
| $CO_2$ emissions from electric vehicles using renewable electricity | Negligible (can be ignored) |
| Average energy consumption of EVs | 12.5 kilowatt-hours per 100 kilometers |

The annual income is derived from Equation (5).

$$\text{Annual Income} = \text{Number of Electric Vehicles} \times \text{Average Annual Kilometer} \times \text{Charging Rate} \quad (5)$$

- Number of electric vehicles: Variable in each scenario
- Average annual kilometers: 4,800 kilometers (400 kilometers per month)
- Charging rate: 0.09 cents
- Annual operational costs: These include maintenance costs of the stations and electricity consumption, which in this study are considered to be approximately 10% of the initial investment cost.

The payback period is calculated using Equation (6).

$$\frac{CAPEX}{\text{NCF}} = Payback\ Period \quad (6)$$

$CAPEX$ The cost is the initial investment.

### 2.3 Analysis method

For each scenario and its respective sub-cases, separate economic and environmental calculations are conducted. These calculations include costs associated with fuel, maintenance, and vehicle purchase, as well as $CO_2$ emissions resulting from fuel consumption and energy supply. Finally, the results are presented comparatively among the scenarios. In the Results section, these calculations are fully examined, and comparisons between the proposed scenarios are carried out.

## 3. Results and discussion

This section analyzes and interprets the economic and environmental results related to the transition from fossil fuel vehicles to electric vehicles in Iran. Using the provided data, three different scenarios for this transition are evaluated. Each scenario is assessed based on economic criteria (e.g., purchase cost, maintenance cost, electricity cost, and return on investment) and environmental criteria (e.g., reduction of greenhouse gas emissions). The ultimate goal is to identify the most suitable strategy for developing electric vehicles in Iran and mitigating the environmental impacts of fossil fuel vehicles.

- **Scenario 1: Base system (only fossil fuel vehicles)**

This scenario serves as the baseline for comparison, and its economic and environmental results are shown in Table 3. The baseline system represents the current conditions with widespread use of fossil fuel vehicles. This scenario imposes substantial economic and environmental costs. Emitting 73 million tons of $CO_2$ annually from road transportation alone poses a significant environmental challenge for Iran. Additionally, annual fuel and maintenance expenses place a heavy financial burden on households and the national economy.

- **Scenario 2: Electric vehicles powered by fossil-fueled electricity**

In this scenario, it is assumed that the electricity required for electric vehicles (EVs) is generated using fossil fuel-based energy sources. The penetration of electric vehicles in this scenario is divided into three levels: 30%, 50%, and 70%.

**Case 1:** 30% Electric vehicles

Table 4 presents the economic and environmental status of the transportation sector, assuming 30% adoption of electric vehicles.

The fuel cost for the remaining fossil fuel vehicles decreases to \$0.63 billion, while the electricity cost for electric vehicles reaches \$0.18 billion. The maintenance cost for electric vehicles amounts to \$0.2 billion. The reduction in $CO_2$ emissions in this scenario is 22,077,160 tons. The required investment for charging infrastructure is \$105,000, with an internal rate of return (IRR) of 29.5%, and a payback period of 5.2 years.

**Table 3.** Current status of Iran's transportation system (baseline scenario)

| Parameter | Value |
|---|---|
| Total number of fossil fuel vehicles | 41 million vehicles |
| Annual fuel consumption of fossil vehicles | 31,851.4 million liters of gasoline |
| Annual fuel cost | $0.9 billion (at a rate of $0.028 per liter) |
| Annual $CO_2$CO_2CO₂ emissions (tons) | 73,257,220 tons $CO_2$CO_2CO₂ (considering 2.3 kg $CO_2$CO_2CO₂ per liter of gasoline consumed) |
| Annual maintenance costs | $1.02 billion ($25 per vehicle) |
| Total annual costs | $1.92 billion (fuel and maintenance costs) |

**Table 4.** Economic and environmental status of transportation in the second scenario, assuming 30% electric vehicle use

| Parameter | Value |
|---|---|
| Number of Electric Vehicles | 12.3 million units |
| Fuel Cost for Remaining Fossil Fuel Vehicles | $0.63 billion |
| Electricity Cost for Electric Vehicles | $0.18 billion (at $0.085 per kilometer for 12.3 million vehicles) |
| Maintenance Cost for Electric Vehicles | $0.2 billion ($16.75 per year for 12.3 million vehicles) |
| Annual CO2CO_2CO2 Emissions from Fossil-Fueled Electricity | 27,720,000 tons $CO_2$CO_2CO₂ (based on 60.8 billion kWh electricity generated from fossil fuel sources) |
| Reduction in CO2CO_2CO2 Emissions | 22,077,160 tons $CO_2$CO_2CO₂ (compared to the baseline scenario) |
| Total Investment in Charging Stations | $105,000 |
| Internal Rate of Return (IRR) | 29.50% |
| Payback Period | 5.2 years |

**Case 2:** 50% Electric vehicles

Table 5 presents the economic and environmental status of the transportation sector, assuming 50% of vehicles are electric. The fuel cost for the remaining fossil fuel vehicles decreases to $0.45 billion, while the electricity cost for electric vehicles rises to $0.3 billion. The maintenance cost for electric vehicles increases to $0.34 billion. The reduction in $CO_2$ emissions reaches 36,760,000 tons. The investment required for charging infrastructure rises to $175,000, with an IRR of 30.2% and a payback period of 5 years.

**Case 3:** 70% Electric vehicles

Table 6 presents the economic and environmental status of the transportation sector, assuming 70% electric vehicle penetration. In this scenario, fuel costs for fossil vehicles decrease to $0.27 billion, while electricity costs for electric vehicles rise to $0.41 billion. The maintenance costs for electric vehicles increased to $0.48 billion, and $CO_2$ emissions decreased by 51,443,040 tons. The investment required for charging infrastructure is $5,000, with an IRR of 30.8% and a payback period of 4.8 years. Despite reduced fuel and maintenance costs, the environmental benefits are limited due to reliance on fossil-based electricity. This highlights the need for a transition to renewable energy sources to fully harness the potential of electric vehicles.

**Table 5.** Economic and environmental status of transportation in the second scenario, assuming 50% electric vehicle use

| Parameter | Value |
|---|---|
| Number of Electric Vehicles | 21 million vehicles |
| Fuel Cost for Remaining Fossil Fuel Vehicles | $0.45 billion |
| Electricity Cost for Electric Vehicles | $0.3 billion (0.085 cents per km for 21million vehicles) |
| Maintenance Cost for Electric Vehicles | $0.34 billion |
| Annual $CO_2$ Emissions from Fossil-Fueled Electricity | 46,200,000 tons $CO_2$ |
| Reduction in $CO_2$ Emissions | 36,760,000 tons $CO_2$ |
| Total Investment in Charging Stations | $175,000 |
| Internal Rate of Return (IRR) | 30.20% |
| Payback Period | 5 years |

**Scenario 3: Electric vehicles with renewable energy**

In this scenario, it is assumed that the electricity consumed by electric vehicles is entirely sourced from solar energy. The impacts of this scenario are evaluated under three levels of electric vehicle penetration: 30%, 50%, and 70%.

**Case 1:** 30% Electric vehicles

Table 7 presents the economic and environmental status of the transportation sector in Scenario 3, assuming 30% adoption of electric vehicles. The fuel cost for the remaining fossil fuel vehicles decreases to 0.63 billion dollars, while the electricity cost for electric vehicles reaches 0.18 billion dollars, and the maintenance cost amounts to 0.2 billion dollars. The $CO_2$ reduction is equivalent to 49,797,160 tons. The required investment for the solar power plant is 480,343.75 dollars, with an internal rate of return (IRR) of 31.67% and a payback period of 5 years.

**Table 6.** Economic and environmental status of transportation in the second scenario, assuming the use of 70% electric vehicles

| Parameter | Value |
|---|---|
| Number of Electric Vehicles | 29million units |
| Fuel Cost for Remaining Fossil Vehicles | $0.27 billion |
| Electricity Cost for Electric Vehicles | $0.41 billion |
| Maintenance Cost for Electric Vehicles | $0.48 billion |
| Annual $CO_2$ Emissions from Fossil Electricity | 64,680,000 tons $CO_2$ |
| Reduction in $CO_2$ Emissions | 51,443,040 tons $CO_2$ |
| Total Investment in Charging Stations | $245,000 |
| Internal Rate of Return (IRR) | 30.80% |
| Payback Period | 4.8 years |

**Table 7.** Economic and environmental status of transportation in the third scenario and assuming the use of 30% electric vehicles

| Parameter | Value |
|---|---|
| Number of Electric Vehicles | 12 million units |
| Fuel Cost for Remaining Fossil Vehicles | \$0.63 billion |
| Electricity Cost for Electric Vehicles | \$0.18 billion |
| Maintenance Cost for Electric Vehicles | \$0.2 billion |
| Investment in Solar Power Plants | \$480343.75 |
| Reduction in $CO_2$ Emissions (tons) | 49,797,160 tons $CO_2$ |
| Rate of Return on Power Plant Investment | 31.67% |
| Payback Period for Power Plants | 5 years |

**Case 2:** 50% Electric vehicles
Table 8 shows the economic and environmental status of the transportation sector in Scenario 3, assuming the use of 50% electric vehicles. The fuel cost for fossil fuel vehicles has decreased to 0.45 billion USD, while the electricity cost for electric vehicles reaches 0.3 billion USD. The maintenance cost increases to 0.34 billion USD, and the reduction in CO2 emissions amounts to 39,837,728 tons. The investment in solar power plants rises to 800,573.75 USD, with an Internal Rate of Return (IRR) of 32.1% and a payback period of 4.8 years.
**Case 3:** 70% Electric vehicles
Table 9 presents the economic and environmental status of the transportation sector in Scenario 3, assuming 70% adoption of electric vehicles.

**Table 8.** Economic and environmental status of transportation in the third scenario, assuming 50% electric vehicle use

| Parameter | Value |
|---|---|
| Number of electric vehicles | 21million units |
| Remaining fuel cost for fossil vehicles | 0.45 billion USD |
| Electricity cost for electric vehicles | 0.3 billion USD |
| Maintenance cost for electric vehicles | 0.34 billion USD |
| Investment in solar power plant | 800,573.75 USD |
| $CO_2$ emission reduction (tons) | 39,837,728 tons $CO_2$ |
| Internal rate of return (IRR) for power plants | 32.10% |
| Payback period for power plants | 4.8 years |

**Table 9.** Economic and environmental status of transportation in the third scenario, assuming 70% use of electric vehicles

| Parameter | Value |
|---|---|
| Number of Electric Vehicles | 29 million units |
| Fuel Cost for Remaining Fossil Fuel Vehicles | 0.27 billion USD |
| Electricity Cost for Electric Vehicles | 0.42 billion USD |
| Maintenance Cost for Electric Vehicles | 0.48 billion USD |
| Investment in Solar Power Plants | 1.12 million USD |
| CO2 Emission Reduction (tons) | 31,870,182 tons $CO_2$ |
| Internal Rate of Return (IRR) | 32.60% |
| Payback Period for Solar Power Plants | 4.6 years |

The fuel cost for fossil fuel vehicles decreases to 0.27 billion USD, while the electricity cost for electric vehicles rises to 0.42 billion USD. Maintenance costs increase to 0.48 billion USD, and $CO_2$ reduction reaches 31,870,182 tons. The investment required for solar power plants reaches 1.12 million USD, with an IRR of 32.6% and a payback period of 4.6 years. This scenario is the most optimal in terms of both environmental and economic factors. In this scenario, due to the use of renewable energy sources, a significant reduction in $CO_2$ emissions is achieved, and a favorable and quick return on investment in solar power plant projects is observed (Figure 2). This scenario highlights the importance of integrating renewable energy sources with the transition to electric vehicles to achieve both economic and environmental sustainability.

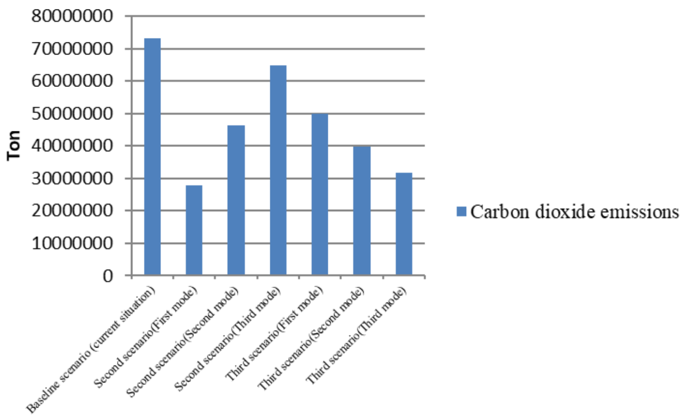


**Figure 2.** Carbon dioxide emissions in different scenarios

The findings of this study demonstrate that electric vehicles have significant potential in reducing economic costs and environmental impacts. The results show that even with fossil fuel-based electricity, the adoption of electric vehicles will lead to a substantial reduction in operational costs and $CO_2$ emissions. However, the greatest environmental benefits are achieved when the electricity used to charge electric vehicles comes from renewable energy sources. An analysis of various electric vehicle penetration scenarios indicates that increasing the share of electric vehicles, coupled with the integration of renewable energy, can result in a substantial reduction in greenhouse gas emissions. Furthermore, investments in charging infrastructure and renewable energy generation provide attractive returns, with payback periods ranging from 4.6 to 5.2 years. As a result, the transition to electric vehicles, supported by renewable energy infrastructure, presents a promising path for economic and environmental sustainability in Iran. To fully capitalize on the benefits of this transition, efforts must be made to accelerate the adoption of electric vehicles and renewable energy sources.

## 4. Conclusion

The findings of this research show that the transition to electric vehicles has a significant impact on reducing economic costs and greenhouse gas emissions. Even in the scenario of using electricity generated from fossil fuels, a reduction of 36.76 million tons of $CO_2$ and an investment return rate of 30.2% reflect the positive impact of this transition. However, the greatest environmental benefits are realized when the electricity used by electric vehicles comes from renewable sources. In this case, a reduction of 114.49 million tons of $CO_2$ and an investment return rate of 32.6% are achieved, showing a remarkable improvement in environmental impact reduction. Additionally, the payback period for solar power plant projects is estimated to be between 4.6 and 5 years, highlighting the economic importance of utilizing renewable energy. An analysis of various scenarios shows that increasing the share of electric vehicles, particularly when combined with the integration of renewable energy, can provide a sustainable solution to reduce dependence on fossil fuels and strengthen energy security. In this process, investment in charging infrastructure and the development of renewable energy are essential. This research emphasizes the importance of precise planning and policymaking to accelerate the transition to electric vehicles and optimally leverage the economic and environmental benefits. Ultimately, the development of electric vehicles alongside renewable energy infrastructure can play a key role in achieving economic and environmental sustainability. This strategy not only leads to a significant reduction in greenhouse gas emissions but also provides a favorable investment return. Therefore, the transition to electric vehicles and the integration of renewable energy present a unique opportunity to reduce environmental impacts, enhance energy security, and achieve sustainable development in Iran.

**Ethical issue**

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

**Data availability statement**

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

**Conflict of interest**

The authors declare no potential conflict of interest.

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**Appendix I**

**Table 1.** Summary of past research on using renewable energy in the transportation sector

| REF | Papers | Results | Research Gap | Challenges | Methods Used |
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| [11] | Management of environmental and economic tradeoffs for the optimization of renewable energy scheme | • The study employed two qualitative methods: bibliometric analysis and systematic literature review, focusing on Scopus-based articles related to renewable energy optimization.<br>• VOSviewer software was utilized to conduct the analysis, which helped in identifying prevalent environmental and economic tradeoffs in renewable energy schemes. | • The study identifies prevalent environmental tradeoffs in renewable energy schemes, such as habitat loss, fragmentation, sediment transportation, and deforestation, but does not explore specific case studies or empirical data that illustrate the extent and impact of these trade-offs in different contexts.<br>• While the research suggests solutions for managing economic tradeoffs like high initial costs and supply chain risks, it lacks a detailed analysis of the effectiveness of these solutions in real-world applications or their potential barriers to implementation. | • The study identifies prevalent environmental tradeoffs in renewable energy schemes, which include habitat loss, fragmentation, sediment transportation, and deforestation, highlighting the negative impacts on ecosystems and biodiversity associated with renewable energy development.<br>• Economic tradeoffs are also discussed, such as high initial costs, intermittency, reliability challenges, job security, resource scarcity, and supply chain risks, which pose significant challenges to the economic viability and stability of renewable energy initiatives. | • The study identified significant environmental tradeoffs in renewable energy schemes, including issues such as habitat loss, fragmentation, sediment transportation, and deforestation, which need to be addressed to enhance sustainability in energy production.<br>• Economic tradeoffs were also highlighted, including high initial costs, intermittency, reliability challenges, job security concerns, resource scarcity, and supply chain risks, leading to the recommendation of strategic planning, continuous monitoring, and diversification of renewable energy sources to manage these challenges effectively. |
| [12] | A Comprehensive Study of Effects of Renewable Energy Based Electric Vehicles on Environment | • The study conducts a thorough analysis of existing literature, empirical studies, and modeling approaches to evaluate the environmental implications of electric vehicles (EVs) powered by renewable energy sources. This comprehensive review helps in understanding the life cycle emissions of EVs compared to conventional cars, considering factors such as production, electricity generation, and end-of-life disposal.<br>• It examines the integration of renewable energy sources like solar, wind, and hydropower into the electrical grid for powering EVs, highlighting the synergistic effects on both the energy and transportation sectors. The study also addresses potential opportunities and challenges associated with the widespread adoption of renewable energy-powered EVs, including infrastructure requirements, legislative incentives, and consumer behavior. | • The study addresses the environmental implications of renewable energy-powered electric vehicles (EVs) but does not explicitly identify specific research gaps or areas that require further investigation, such as the long-term impacts of EV adoption on biodiversity or the socio-economic effects on communities transitioning to renewable energy sources.<br>• While the paper discusses the integration of renewable energy sources into the electrical grid for powering EVs, it does not delve into the technological advancements or innovations needed to enhance this integration, nor does it explore the potential barriers to widespread adoption of such technologies in different regions. | • The study addresses potential challenges associated with the widespread adoption of electric vehicles (EVs) powered by renewable energy, including infrastructural needs that must be met to support the integration of EVs into existing transportation networks and the electrical grid.<br>• It also highlights the importance of legislative incentives and customer behavior as factors that could influence the successful implementation and acceptance of renewable energy-powered EVs, indicating that these elements may pose challenges to achieving a sustainable transition in transportation. | • The study highlights that electric vehicles (EVs) powered by renewable energy sources can significantly reduce air pollution and greenhouse gas emissions compared to conventional internal combustion engine vehicles, emphasizing the potential for cleaner transportation networks as the world shifts towards greener energy solutions.<br>• It provides insights into the life cycle emissions of EVs, comparing them to traditional cars by considering factors such as manufacturing processes, electricity generation methods, and end-of-life disposal, ultimately guiding decision-making for sustainable transportation and energy transitions. |

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| [13] | The environmental footprint of transport by car using renewable energy | • The paper compares and contrasts the carbon, land, and water footprints per driven kilometer in midsize cars that utilize different energy sources, including conventional gasoline, biofuels, bioelectricity, solar electricity, and solar-based hydrogen.<br>• The analysis focuses on assessing the environmental impacts of these various fuel types to understand the trade-offs involved in replacing fossil fuels with renewable energy in the transport sector. | | • The transition from fossil fuels to renewable energy in the transport sector may lead to trade-offs concerning land and water resources, which could impact environmental sustainability.<br>• While renewable energy sources can lower greenhouse gas emissions, the environmental footprints associated with different fuel types vary significantly, with biofuel-driven cars exhibiting the largest footprints compared to solar-powered electric and hydrogen cars. | • Solar-powered electric cars have the smallest environmental footprints per kilometer driven, indicating they are the most sustainable option among the alternatives analyzed.<br>• Biofuel-driven cars have the largest environmental footprints per kilometer, suggesting that while they are an alternative to fossil fuels, they may not be the most environmentally friendly choice. |
| [14] | Renewable energy systems implementation in road transport: prospects and impediments | • The paper conducts a detailed literature review to assess the current state of major renewable energy systems in road transport, focusing specifically on the European Union. This review includes an analysis of the prospects and impediments for the future use of biofuels, renewable electricity, and green hydrogen in road transport.<br>• The authors discuss the implications of various policies implemented and emission reduction targets set for the future, particularly in relation to passenger car transport, to provide a comprehensive overview of the challenges and opportunities for renewable energy systems in the transport sector. | • The paper highlights that most literature focuses either solely on biofuels, battery electric vehicles, or hydrogen and fuel cell vehicles, indicating a research gap in comprehensive analyses that consider all these renewable energy systems together. This lack of integrated studies limits the understanding of the overall potential and challenges of renewable energy systems in the transport sector.<br>• There is a noted immaturity in the production processes of advanced biofuels, which could be produced from lignocellulosic materials and do not compete with food production. The paper suggests that further research is needed to improve these production processes and reduce costs, indicating a gap in the development and commercialization of advanced biofuels. | • The high investment costs associated with BEVs and FCEVs present a significant barrier to their faster market penetration. Although these costs may decrease in the future due to technological advancements, they currently hinder the widespread adoption of these alternative automotive technologies.<br>• The competition for arable land between biofuels production and food/feed production poses a critical challenge for the future of renewable energy in the transport sector. The sustainability issues related to biofuels, particularly the ILUC, complicate their viability as a low-carbon fuel option, raising concerns about their overall environmental benefits. | • The paper concludes that while there are prospects for increased use of RES in the transport sector, particularly in the EU, the overall life-cycle emissions must be carefully considered to avoid negative environmental impacts, such as those associated with the Green Paradox. The competition between biofuels and food production is highlighted as a critical issue for the future of biofuels.<br>• It identifies high investment costs as a significant barrier to the faster market penetration of BEVs and FCEVs. Although the number of BEVs is increasing globally, the costs of green hydrogen remain prohibitively high compared to fossil fuel-derived hydrogen, which limits the growth of hydrogen and fuel cell technologies in the automotive sector. |

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| [15] | Enhancing the utilization of renewable generation on the highway with mobile energy storage vehicles and electric vehicles | • The paper proposes a co-optimization method for the EVcharging scheme and MESV scheduling on the highway, which takes into account locational marginal price, renewable generation, and the benefits for EV users.<br>• A bi-level optimization model is developed to simulate the interaction between EV users and the HO, where the upper-level model focuses on optimizing EV charging pricing and MESV scheduling to maximize HO profit, while the lower-level model aims to minimize EV users' charging-parking costs. | • The paper does not address the potential impacts of varying traffic patterns and their influence on the scheduling of MESVs and EV charging loads, which could affect the overall efficiency of the proposed co-optimization method.<br>• There is a lack of exploration into the integration of different types of renewable energy sources and their specific characteristics, which may further enhance the utilization of renewable generation on the highway beyond the current focus on scheduling MESVs and EV charging. | • The paper discusses the challenge of reshaping EV charging loads to address the imbalance between energy supply from renewable generation and the electricity demand from traffic on the highway. This imbalance is expected to grow with the increasing number of EVs and renewable energy sources.<br>• Another challenge highlighted is the optimization of scheduling MESVs to consume renewable energy effectively. This involves developing a co-optimization method that considers various factors such as locational marginal price, renewable generation, and the benefits to EV users, which complicates the scheduling and charging strategies. | • The study demonstrates a 32.0% increase in the utilization of renewable energy on the highway, indicating a significant improvement in the integration of renewable generation with electric vehicle charging demands.<br>• There is a reduction of 3190.1 kWh in electricity purchased from the main grid, which contributes to promoting both environmental and economic sustainability for the highway operator. |
| [16] | Optimization of renewable energy usage in public transportation: Mathematical model for energy management of plug-in PV-based electric metrobuses | • The study employs a Metrobus Charging Station Optimization Model that integrates grid and renewable energy systems, allowing for energy exchange with the grid when necessary. This model is specifically designed for the IETT Avcılar Metrobus garage in Istanbul, focusing on static conditions and optimal scheduling.<br>• A single objective MILP approach is utilized to maximize the usage of renewable energy while minimizing the cost associated with non-renewable energy usage. The model also determines the best assignment of metrobuses to their scheduled departures, ensuring an environmentally friendly and cost-effective solution. | • The study focuses specifically on the optimization of renewable energy usage in the context of metrobuses in Istanbul, Turkey, but does not address the potential applicability of the proposed model to other cities or public transportation systems, which could limit the generalizability of the findings.<br>• While the model aims to maximize the usage of renewable energy and minimize costs, it does not explore the long-term impacts of integrating such systems on the overall sustainability of public transportation or the potential challenges in implementation, such as infrastructure requirements or policy support. | • The paper highlights the challenge of reducing carbon emissions from public transportation systems that traditionally rely on internal combustion engines, emphasizing the need for greener solutions to meet sustainability targets and decrease the carbon footprint associated with these vehicles.<br>• Another challenge addressed is the optimization of energy management for electric metrobuses, specifically in the context of integrating renewable energy systems with the grid, which requires effective scheduling and assignment of metrobuses to ensure maximum utilization of renewable energy while minimizing costs associated with non-renewable energy usage. | • The study developed a Metrobus Charging Station Optimization Model that integrates renewable energy systems with the grid, allowing for energy exchange when necessary, specifically designed for the IETT Avcılar Metrobus garage in Istanbul. This model focuses on maximizing the usage of renewable energy while minimizing the costs associated with non-renewable energy usage.<br>• The model was solved using the GAMS solver, and the results indicated that adopting an environmentally friendly approach to public transportation through the electrification of metrobuses is not costly, demonstrating the feasibility of sustainable energy management in public transport systems. |

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| [17] | A Review of the Integrated Renewable Energy Systems for Sustainable Urban Mobility | • The paper reviews various renewable energy integration methods for electric vehicle charging stations, including the use of CPVT systems, wind turbines, and biomass-based Rankine cycles to generate electricity and thermal energy for vehicle charging and hydrogen production.<br>• It discusses the prioritization of energy storage systems, starting with hydrogen fuel cells, followed by ammonia fuel cells, and lastly conventional battery storage, to ensure a reliable power supply for electric vehicles when renewable energy generation is insufficient. | • The paper highlights the challenges of integrating renewable energy into existing electric power systems, pointing out the technical and economic difficulties due to the varying and unreliable nature of renewable energy sources compared to traditional methods.<br>• The research identifies the need to understand the three main operational planning scopes crucial to renewable energy integration before considering how renewable resources impact these planning processes, indicating a gap in comprehensive understanding and analysis in this area. | • The integration of renewable energy into existing electric power systems is technically and economically challenging due to the ingrained nature of these systems in daily life and the variability and unreliability of renewable energy sources compared to traditional methods.<br>• There are several implementation challenges related to consumer incentives, infrastructure, and the need for a sustainable energy supply for charging stations in urban regions, which are crucial for promoting the use of cleaner vehicles and reducing pollution. | • The paper highlights the adverse impacts of air pollutants emitted from internal combustion engine vehicles, emphasizing the need for transitions to cleaner fuels and electric vehicles to reduce pollution and encourage the use of clean vehicles for urban mobility.<br>• It discusses the integration of electric vehicle stations with renewable energy sources, showcasing how certain components within the integrated system can provide uninterrupted power supply to electric vehicles, leading to less pollution and promoting the adoption of clean vehicles. |
| [18] | Externalities of transportation fuels: Assessing trade-offs between petroleum and alternatives | • The study utilized the GREET life-cycle analysis model to assess the environmental externalities associated with different types of transportation fuels, providing a comprehensive evaluation of their impacts throughout their life cycles.<br>• Additionally, the research employed several other models, including the FASOM-GHG model for agriculture and forestry, the APEEP integrated assessment model for calculating the marginal damage of emissions, the GTAP-BIO computable general equilibrium model for estimating land use changes, and the OSIRIS model for estimating species extinctions due to deforestation. | • The study indicates that many previous analyses have not included all elements that constitute the true cost of oil, suggesting a gap in comprehensive assessments of oil dependence costs across various studies. This highlights the need for more inclusive research that captures the full spectrum of economic and environmental impacts associated with oil consumption.<br>• There is a call for a holistic framework to assess the relative costs and benefits of alternative transportation fuels, indicating a gap in existing research methodologies that fail to integrate economic, environmental, and societal costs comprehensively. This suggests that future studies should aim to develop and apply such frameworks to better inform policy initiatives related to transportation infrastructure. | • Achieving energy security by reducing dependence on imported oil is highlighted as a foremost challenge for the United States, which currently imports about 50 percent of its oil consumption, accounting for 25 percent of world oil consumption.<br>• The study indicates that many existing analyses do not account for the full range of costs associated with oil dependence, suggesting that a comprehensive understanding of these costs is necessary for effective policy-making regarding transportation fuels. | • The study estimates the costs associated with energy security and the dependence on oil, highlighting that many studies have not fully accounted for the true costs of oil, which include various economic and environmental factors.<br>• The research utilizes multiple models, such as GREET and APEEP, to assess environmental externalities of different transportation fuels, suggesting a need for a holistic framework to evaluate the relative costs and benefits of alternative fuels for future energy needs. |

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| [19] | Energy System Implications of Demand Scenarios and Supply Strategies for Renewable Transportation Fuels | • The paper employs a combination of bottom-up and top-down energy modeling approaches to address shortcomings in energy planning for renewable transportation fuels. This dual methodology allows for a more comprehensive analysis of energy demands and supply strategies.<br>• The study designs a set of eight scenarios that vary in climate ambition, the share of indirect electrification of transport final energy demand, and biofuel availability, enabling a detailed examination of the implications of different demand scenarios on energy supply infrastructure. | • The impacts of sustainable biofuels on the required electricity supply infrastructure are not well understood, indicating a gap in knowledge regarding how biofuel availability influences energy demand and infrastructure needs in the transport sector.<br>• There is a lack of sufficient justification for the assumption of large shares of imported gaseous and liquid energy carriers, which neglects the needs of local societies and highlights a gap in addressing the socio-economic implications of renewable fuel imports in energy planning. | • The transport sector faces significant challenges in reducing greenhouse gas (GHG) emissions due to the complex interplay of social behavioral, technical factors, political decisions, and economic conditions, necessitating detailed sub-sector demand modeling for effective energy planning.<br>• The energy supply for climate-neutral transportation services is expected to strain electricity supply infrastructure, with studies often overlooking local societal needs while assuming large shares of imported renewable fuels, highlighting a gap in understanding the impacts of sustainable biofuels on electricity supply infrastructure. | • The study finds that bottom-up demand modeling of transport final energy demand significantly narrows down the ranges of renewable fuel energy demands that were previously assumed in top-down approaches. This indicates that more accurate demand modeling can lead to better energy planning and infrastructure development.<br>• The availability of biofuels may considerably reduce the demand for e-fuels, which in turn lowers the required expansion of energy infrastructure. This results in a more gradual distribution of renewable energy expansions over the next 25 years and reduces the cost-optimal hydrogen production capacity and necessary grid expansion in Germany beyond 2030. |
| [20] | Electric Vehicles and Renewable Energy | • The paper discusses various charging methods for electric vehicles, including home solar systems, public charging stations with renewables, and smart charging systems.<br>• It highlights the importance of integrating electric vehicles with renewable energy sources like solar, wind, and hydropower to minimize their carbon footprint and promote sustainability. | | | • The paper demonstrates that the environmental impact of electric vehicles (EVs) is significantly influenced by the source of their electricity, highlighting the importance of renewable energy sources such as solar, wind, and hydropower in reducing the carbon footprint of EVs.<br>• It presents the advantages of electric vehicles over gasoline vehicles, including lower maintenance needs, cost-effectiveness, quieter operation, energy efficiency, and a positive impact on air quality, thereby promoting the transition towards a more sustainable and environmentally friendly energy landscape. |

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| [21] | Energy Saving in Public Transport Using Renewable Energy | • The paper evaluates the economic viability of hydrogen production through a discounted cash flow analysis, considering two different hypotheses: one focusing on the installation of a hydrogen station powered by grid electricity and the other incorporating the initial investments of renewable energy sources (biomass, wind, and sea wave) alongside the hydrogen station.<br>• Hydrogen production is primarily analyzed through the electrolysis process, which utilizes electrical energy supplied by various renewable sources, including wind, biomass, and sea wave, to generate hydrogen, thereby facilitating the replacement of diesel buses with hydrogen-powered vehicles in urban transport. | • The paper does not provide a comprehensive analysis of the long-term sustainability and economic viability of the proposed hydrogen production methods, particularly regarding the operational and maintenance costs of the renewable energy sources (wind, biomass, and sea wave) over time, which could impact the overall feasibility of the project.<br>• There is a lack of detailed exploration into the potential challenges and limitations associated with the implementation of hydrogen filling stations and the infrastructure required for supporting fuel cell vehicles, including regulatory, logistical, and technological barriers that may arise in the transition from diesel to hydrogen-powered public transport. | • The variability of the sea wave energy source presents a challenge, as its availability is higher during the winter season and lower in the summer season. This variability can be addressed through the use of appropriate storage tanks to ensure a consistent supply of energy for hydrogen production.<br>• The economic analysis of the hydrogen production system requires consideration of initial investments for the biomass power plant, wind farm, wave farm, and hydrogen station. The viability of the project depends on accurately estimating these costs and the potential avoided purchase of fossil fuels, which complicates the financial planning and investment decisions. | • The study demonstrates that utilizing renewable energy sources such as wind, biomass, and sea waves for hydrogen production can effectively replace the entire fleet of diesel-powered buses in Trapani with hydrogen vehicles, leading to significant reductions in greenhouse gas emissions. In the best-case scenario, the annual avoided emissions are quantified as 1444 tons of $CO_2$, 7.64 tons of CO, 1.12 tons of $PM_{10}$, 2.1 tons of NMVOC, and 22.85 tons of $NO_x$.<br>• The economic analysis indicates that while the production of hydrogen from a self-sufficient renewable energy plant is not economically viable without incentives, the discounted cash flow for purchasing electrical energy for hydrogen production becomes comparable within five years under different scenarios, highlighting the financial challenges associated with transitioning to hydrogen fuel in public transport. |
| [22] | Renewable Energy Generation and Impacts on E-Mobility | | | • The paper highlights the need for a fundamental change in the road transportation sector to achieve a long-term transition to a low-carbon economy, which poses challenges in adapting existing infrastructure and services to meet demographic and economic growth without increasing pollution and congestion.<br>• It emphasizes the requirement for affordable, secure, and inclusive sustainable solutions that are integrated with customer-centric infrastructure, indicating the challenge of developing such systems while ensuring they are efficient and effective for all users. | • The paper highlights that the integration of Electric Vehicles (EVs) with Renewable Energy Sources can significantly reduce future emissions of greenhouse gases and air pollutants from road transport, contributing to a long-term transition to a low-carbon economy.<br>• It emphasizes the necessity for a fundamental change in the road transportation sector, advocating for the development of affordable, secure, and sustainable infrastructure and services that are customer-centric, in order to adapt to demographic and economic growth while minimizing pollution and congestion. |

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| [23] | Do patents, renewable energies and energy taxes in the transport sector reduce transportation carbon emissions in the European Union? | • The study analyzes the impact of renewable energy use, patent development, and energy taxes in the transport sector on the three different modes of transport-related emissions (aviation, road, and rail) in the 10 highest-income countries of the European Union over the period 2008–2020.<br>• The study uses the novel half-panel jackknife estimator for the analysis of the impact of patents, renewable energies, and energy taxes on carbon dioxide (CO2) emissions in the transportation sector. | | • The transportation industry in the European Union has not succeeded in reducing greenhouse gas emissions, making it the sole economic sector with increasing emissions, which poses a significant challenge in meeting climate targets.<br>• The study highlights the need for effective strategies, such as promoting electric vehicles and eco-friendly transportation through energy taxes, and supporting renewable energy sources and patents for green innovations, to address the ongoing issue of $CO_2$ emissions in various modes of transport. | • Patents have been found to contribute to the reduction of CO2 emissions specifically in aviation and rail transportation, indicating that innovation in these sectors can lead to lower greenhouse gas emissions.<br>• Renewable energies are effective in reducing emissions only in rail transportation, while energy taxes are effective in mitigating CO2 emissions in road transportation, suggesting that different strategies may be needed for different modes of transport. |
| [24] | Reducing transport sector CO2 emissions patterns: environmental technologies and renewable energy | • The research employs panel corrected standard error methods to analyze the data, which helps in addressing potential issues of heteroscedasticity and autocorrelation in the panel data set.<br>• Additionally, feasible generalized least squares methods are utilized to estimate the relationships between environmental technologies, renewable energy, and CO2 emissions, allowing for more efficient and consistent parameter estimates in the presence of panel data characteristics. | • The research does not explicitly identify specific gaps in existing literature or methodologies related to the impact of environmental technologies and renewable energy on CO2 emissions in the EU transport sector, which could provide a clearer context for the study's contributions and limitations.<br>• There is a lack of detailed exploration into the socio-economic factors that may influence the adoption of renewable energy and environmental technologies in transportation, which could affect the overall effectiveness of the proposed strategies for emission reduction. | • The study emphasizes the necessity for heightened EU investment in sustainable transport infrastructure and clean energy solutions, indicating that a lack of investment could hinder the adoption of environmental technologies and renewable energy, which are crucial for reducing CO2 emissions in the transport sector.<br>• It highlights the need for a multifaceted approach that includes comprehensive strategies for cleaner transportation, innovation, and education, suggesting that without these elements, the transition towards sustainable practices in the EU may be slowed or obstructed. | • The study reveals a significant and variable effect of environmental technologies and renewable energy on CO2 emissions in the EU transport sector, indicating that increased adoption of renewable energy is positively correlated with emission reduction.<br>• The research emphasizes the necessity for heightened EU investment in sustainable transport infrastructure and clean energy solutions, recommending initiatives such as electric vehicles, hydrogen fuel cells, and biofuels to align with the goals of the European Green Deal and the EU Climate Law. |

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| [25] | Utjecaj obnovljivih izvora energije na prijevoz | • The paper discusses the use of photovoltaic modules in various vehicles, including solar and biodiesel vehicles, highlighting their ability to convert solar energy into electricity to power electric motors and other devices within the vehicles. This method emphasizes the importance of renewable energy sources in reducing greenhouse gas emissions and promoting environmental protection.<br>• It also examines the integration of solar technology in marine applications, where photovoltaic modules are used to maintain battery charge levels in boats, addressing the increasing demand for electricity during periods of inactivity and preventing battery damage, thereby extending their lifespan. | • The paper does not explore the economic feasibility and cost-effectiveness of implementing renewable energy sources in transportation, particularly in comparison to traditional fossil fuels. A detailed analysis of the financial implications for consumers and manufacturers could provide insights into the broader adoption of these technologies.<br>• There is a lack of discussion on the long-term sustainability and environmental impact of the production and disposal of renewable energy vehicles, such as solar and electric vehicles. Research could focus on the lifecycle assessment of these vehicles, including the sourcing of materials, manufacturing processes, and end-of-life recycling or disposal methods. | • Not all renewable energy technologies are perfect, indicating that while they contribute significantly to environmental protection, there are still limitations and challenges in their efficiency and implementation in the transport sector.<br>• Electric vehicles, although environmentally friendly, face challenges related to their range and the need for recharging, which can limit their practicality compared to hybrid vehicles that can utilize both electric and fossil fuel power sources. | • The increasing use of renewable energy sources in transportation, such as solar and biodiesel vehicles, significantly reduces greenhouse gas emissions, contributing to environmental protection and addressing global warming caused by non-renewable energy depletion.<br>• The integration of photovoltaic systems in vehicles, including boats, enhances battery longevity and efficiency, particularly during periods of inactivity, thereby addressing common issues related to battery depletion and damage, which ultimately supports the sustainability of marine and land transportation. |
| [26] | Economic and environmental multi-objective optimisation to evaluate the impact of Belgian policy on solar power and electric vehicles | • The research employs a multi-objective branch and bound algorithm, originally developed by Mavrotas and Diakoulaki, which has been improved for the bi-objective case. This algorithm is designed to find all efficient solutions of multi-objective mixed integer linear programming (MOMILP) problems exactly, ensuring that the solutions are not dominated by any other feasible solutions.<br>• The methodology distinguishes between energy generating technologies and transportation technologies, incorporating constraints that account for economies of scale. The model uses binary variables to indicate active technology intervals, allowing for a structured comparison of the economic and environmental impacts of various energy and transportation technologies while satisfying specific demand constraints. | • The paper acknowledges the limitations of the model, particularly in differentiating between rational investors who consider life cycle costs and bounded rational investors who focus on required investments only. This distinction suggests a gap in understanding how different investor behaviors impact the adoption of energy and transportation technologies under varying policy measures.<br>• The research highlights the need for further exploration of the impact of subsidies on the Pareto frontier, indicating a gap in assessing how different subsidy structures could influence the optimal mix of energy and transportation technologies, particularly in terms of economic and environmental outcomes. | • The paper highlights the challenge of differentiating between rational investors, who consider life cycle costs, and bounded rational investors, who often focus solely on required investments. This distinction affects the effectiveness of current policy measures aimed at promoting technologies like solar power and electric vehicles.<br>• Another challenge discussed is the limitation of grid-powered battery electric vehicles (BEVs) in significantly reducing greenhouse gas (GHG) emissions compared to solar panels, despite their lower costs. This raises questions about the optimal mix of technologies and the impact of policy on achieving environmental goals. | • The research demonstrates the use of multi-objective mixed integer linear programming (MOMILP) to identify optimal solutions for energy and transportation technologies, highlighting the differences in outcomes when considering the minimisation of total economic life cycle costs versus solely the initial investment. The results are illustrated through the Pareto frontier, which shows the trade-offs between life cycle emissions and life cycle costs, both with and without the impact of policy measures.<br>• The findings indicate that current policy measures effectively target rational investors who prioritize life cycle costs, while private investors, who may exhibit bounded rationality, tend to focus on required investments. This distinction reveals the limitations of policy effectiveness in addressing the needs of all investor types, particularly in the context of reducing greenhouse gas emissions through the adoption of various energy and transportation technologies. |

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| [27] | The Effectiveness and Trade-Offs of Renewable Energy Policies in Achieving the Dual Decarbonization Goals in China: A Dynamic Computable General Equilibrium Analysis | • The study employs a dynamic general equilibrium model to assess the effectiveness and trade-offs of various renewable energy policies in achieving China's dual decarbonization goals by 2060. This model captures both direct and indirect effects of changes in the economy and identifies impact mechanisms across different sectors.<br>• An indicator measuring the efficiency of carbon emission abatement is calculated by dividing the percentage changes in China's GDP by the amount of carbon emission abatement. This indicator helps evaluate the average economic loss associated with abating per billion tons of CO2 through renewable energy policies, allowing for a comparative analysis of the policies' impacts on GDP and carbon emissions. | • The paper highlights that previous studies have shown great disparity in the effectiveness and suitability of renewable energy policies in abating carbon emissions, indicating a lack of consensus and comprehensive understanding in the existing literature regarding the impact of these policies on carbon reduction.<br>• While the study evaluates the effectiveness and trade-offs of various renewable energy policies, it acknowledges that the implications and limitations of the results are discussed, suggesting that further research is needed to explore the long-term effects and potential unintended consequences of these policies on the economy and energy structure. | • The effectiveness of renewable energy policies in abating carbon emissions varies significantly, with some policies like the Renewable Energy Cost (REC) showing greater effectiveness in reducing CO2 emissions while also benefiting GDP, whereas others like the Carbon Market (CRP) and Renewable Portfolio Standards (REP) can lead to greater GDP losses despite their ability to reduce emissions.<br>• Most renewable energy policies tend to sacrifice internal and external demand in the economy, which poses a challenge for policymakers who must balance the need for carbon emission reductions with the potential negative impacts on economic growth and demand. | • The study finds that renewable energy policies could abate China's CO2 emissions by 2.57 billion tons by 2060, with varying effectiveness among the policies. The reduction of renewable energy costs (REC) is identified as the most effective policy, followed by renewable portfolio standards (REP) and carbon market (CRP).<br>• While most renewable energy policies may lead to a sacrifice in China's internal and external demand, they are expected to benefit employment and cause relatively slight damage to the GDP, with the REC actually raising GDP by 1.1713%. |
| [28] | A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies | | • The paper does not explicitly identify specific research gaps, but it implies a need for further exploration into the economic feasibility of producing renewable transportation fuels on a large scale from domestic resources, as well as the technological advancements required to enhance the efficiency of vehicles that utilize these fuels.<br>• There is a lack of detailed analysis on the integration of renewable fuels with existing transportation infrastructure and the potential challenges that may arise in transitioning from petroleum-based fuels to renewable alternatives, particularly in terms of supply chain logistics and consumer acceptance. | • The current transportation system is heavily reliant on petroleum-based fuels, making it vulnerable to supply and price volatility in the world oil market, which poses a significant challenge for energy security and stability.<br>• Despite advancements in reducing tailpipe emissions, motor vehicles still contribute significantly to urban air pollution and greenhouse gas emissions, indicating a need for the development and adoption of lower-polluting alternatives to internal combustion engines. | • The paper highlights that transitioning to renewable transportation fuels derived from sources such as solar, wind, hydropower, and biomass could significantly reduce greenhouse gas emissions and local air pollutants, especially when used in zero or near-zero emission vehicles like battery-powered electric vehicles or fuel cell electric vehicles.<br>• It emphasizes the potential for large-scale economic production of renewable fuels from domestic resources, which could alleviate the vulnerabilities associated with petroleum-based fuels and contribute to a more sustainable and environmentally friendly transportation system. |