Fueling the Future or Stuck in the Past? A Physics-Driven and Economic Expedition into Electric, Hydrogen, HVO, and Petrol Propulsions

Oliver Bodemer

December 7, 2023

Abstract

Ah, the game is afoot once more! Following the trail blazed by the enlightening tome Comparative Analysis of Electric Cars and Diesel Cars Using Hydrotreated Vegetable Oil (HVO), we find ourselves embarking upon a most intriguing investigation. Our quarry? No less than four of the most cunning and elusive beasts in the automotive kingdom: electric, hydrogen, hydrotreated vegetable oil (HVO), and the venerable petrol.

With the meticulous eye of a detective and the precision of a scientist, we delve into the very sinews and bones of these mechanical creatures. We shall dissect their physical efficiencies with the keen blade of physics, leaving no gear unturned, no circuit unexamined. From energy conversion to fuel consumption, we shall lay bare their secrets.

But, my dear Watson, the plot thickens! For we shall not stop at mere physical scrutiny. No, we shall don our economist’s hat and weigh their worth in gold, assessing cost-effectiveness, market trends, and the long-term financial implications that would make even the Bank of England take notice.

And let us not forget the environment, that great and silent witness to all our deeds. We shall examine emissions, sustainability, and ecological footprints with the thoroughness of a bloodhound on the scent.

Our aim? To present an objective comparison, as clear and as illuminating as the gaslights of Baker Street, highlighting strengths, limitations, and the tantalizing possibilities that lie ahead. The findings, I have no doubt, will be of great interest to stakeholders, policymakers, and all those engaged in the grand debate on sustainable transportation. The game, as they say, is truly afoot!
Ah, the game is afoot once more! Following the trail blazed by the enlightening tome 'Comparative Analysis of Electric Cars and Diesel Cars Using Hydrotreated Vegetable Oil (HVO)' [6], we find ourselves embarking upon a most intriguing investigation. Our quarry? No less than four of the most cunning and elusive beasts in the automotive kingdom: electric, hydrogen, hydrotreated vegetable oil (HVO), and the venerable petrol.

With the meticulous eye of a detective and the precision of a scientist, we delve into the very sinews and bones of these mechanical creatures. We shall dissect their physical efficiencies with the keen blade of physics, leaving no gear unturned, no circuit unexamined. From energy conversion to fuel consumption, we shall lay bare their secrets.

But, my dear Watson, the plot thickens! For we shall not stop at mere physical scrutiny. No, we shall don our economist’s hat and weigh their worth in gold, assessing cost-effectiveness, market trends, and the long-term financial implications that would make even the Bank of England take notice.

And let us not forget the environment, that great and silent witness to all our deeds. We shall examine emissions, sustainability, and ecological footprints with the thoroughness of a bloodhound on the scent.

Our aim? To present an objective comparison, as clear and as illuminating as the gaslights of Baker Street, highlighting strengths, limitations, and the tantalizing possibilities that lie ahead. The findings, I have no doubt, will be of great interest to stakeholders, policymakers, and all those engaged in the grand debate on sustainable transportation. The game, as they say, is truly afoot!

Introduction
Overview of the Study
"Ah, the transportation sector, that vast and bustling empire of comings and goings, finds itself at a crossroads, a veritable Waterloo, if you will. The world clamors for propulsion systems that are not only sustainable but also efficient, as if asking for the moon on a stick. This study, my dear friends, is a veritable odyssey into the heart of four such systems: electric, hydrogen, hydrotreated vegetable oil (HVO), and the good old petrol. Building upon the seminal work 'Comparative Analysis of Electric Cars and Diesel Cars Using Hydrotreated Vegetable Oil (HVO)' [6], we embark on a deeper exploration, delving into the mysteries of physics and the enigmas of economics that shroud these propulsion systems.

Objectives and Scope
Our quest, should we choose to accept it, is to unravel the Gordian knot of physical efficiency, to weigh the economic impact in the scales of justice, and to ponder the environmental implications of these modern chariots. Electric, hydrogen, HVO, and petrol - each shall pass under our magnifying glass. We shall dissect their energy conversion, scrutinize their fuel consumption, and assess their cost-effectiveness with the precision of a Swiss watchmaker. Market trends, emissions, sustainability - nothing shall escape our inquisitive gaze.

Research Questions
halcyon days of motoring, steam reigned supreme, much like the great steamships that crossed the Atlantic. But, as with all great empires, its time waned, giving way to the rise of the internal combustion engine (ICE), those roaring beasts powered by petrol and diesel. Yet, as the wise often say, every rose has its thorn, and the ICE was no exception. Emissions, that invisible specter, and the insatiable thirst for fuel led to a quest for alternatives [36].

Enter the electric vehicle (EV), a chariot of modernity, promising cleaner skies and a more efficient journey. And let us not forget the hydrogen fuel cell vehicles (FCVs), those paragons of zero emissions, and hydrotreated vegetable oil (HVO), a knight in shining armor for the diesel engine, reducing our reliance on the black gold that lies beneath [33], [47].

Current State of Electric, Hydrogen, HVO, and Petrol Vehicles
Electric vehicles, those silent sentinels of the roads, have captured the hearts of many, bolstered by advancements in the alchemy of batteries, the benevolence of governments, and a growing chorus of environmental consciousness. Yet, they are not without their Achilles’ heel - range, charging stations, and the longevity of their battery hearts [4].

Hydrogen fuel cell vehicles, though less numerous, offer the promise of swift refueling and journeys as long as the horizon. But, alas, the cost of their fuel cell hearts and the need for a network of hydrogen wells remain challenges to be conquered [23].

HVO, the green alternative to the diesel of old, has found its place in the sun. Compatible with the engines of yore, it reduces the specter of greenhouse gases. Yet, the golden elixir is not without its trials - availability and cost [15].

Petrol vehicles, those stalwarts of the road, continue their reign, albeit challenged. Advances in the art of the ICE have brought forth improvements, but the winds of change are blowing, heralding a shift to cleaner steeds [22].

Previous Studies and Their Findings
Scholars and sages have long debated and studied these mechanical steeds. Jones et al. (2018) sang praises of the electric vehicle’s efficiency and its boon to the environment, compared to its ICE brethren [25]. Smith and Johnson (2020) extolled the virtues of hydrogen fuel cell vehicles in their crusade against greenhouse gases [44].

Studies on HVO have illuminated its potential in reducing the carbon footprint and its camaraderie with diesel engines of old [17]. Yet, they also whisper of challenges in its creation and availability [1].

Comparative studies on petrol vehicles have sounded the clarion call for a transition to cleaner alternatives, despite the advancements in the realm of ICE [9].

Methodology
Data Collection Methods

Data collection for this study involved a comprehensive approach, encompassing both primary and secondary sources. Primary data was gathered through experimental testing of vehicle models, including the Tesla Model 3 Long Range, Mercedes C 300 d 4Matic, Mercedes C 200 4Matic, and Hyundai Nexo. These tests focused on measuring performance metrics such as acceleration, top speed, and fuel efficiency. Secondary data was collected from a variety of sources, including manufacturer specifications, scientific journals, and industry reports, to provide a broader context for the performance and efficiency of the vehicles [14], [13].

Analytical Techniques
The analytical techniques employed in this study involved both qualitative and quantitative methods. Quantitative analysis included statistical methods to evaluate the performance and efficiency data collected from the vehicle tests. This involved calculating averages, standard deviations, and conducting comparative analyses between the different propulsion systems. Qualitative analysis was used to assess the environmental impact and economic implications of each propulsion system, drawing on existing literature and industry reports [28], [31].

Assumptions and Limitations
Several assumptions were made in this study. It was assumed that the vehicles were operating under optimal conditions and that the data collected from secondary sources was accurate and reliable. Additionally, the environmental impact assessment was based on available data, which may not encompass all possible variables. The study also has limitations, including the scope of vehicles tested and the potential variability in performance due to external factors such as weather conditions and driving habits [29].

Theoretical Framework
Physics of Vehicle Propulsions
The physics of vehicle propulsion involves understanding the energy conversion processes that power a vehicle. For electric vehicles (EVs), this involves the conversion of electrical energy stored in batteries to mechanical energy. The efficiency of this process is influenced by factors such as battery technology and the efficiency of electric motors [43].

Hydrogen fuel cell vehicles (FCVs) convert chemical energy from hydrogen into electrical energy through a fuel cell. The efficiency of this process depends on the fuel cell technology and the hydrogen storage system [24].

For vehicles using hydrotreated vegetable oil (HVO) and petrol, the internal combustion engine (ICE) plays a crucial role. The efficiency of ICEs is determined by the engine design, fuel type, and combustion process. HVO, being a cleaner-burning fuel, can potentially improve the efficiency and reduce emissions of diesel engines [16].

Economic Theories Related to Vehicle Propulsions
Economic theories related to vehicle propulsion focus on the cost-benefit analysis of different propulsion systems. This
includes the initial purchase cost, fuel or energy costs, maintenance, and potential subsidies or incentives. Electric vehicles, while having a higher initial cost, benefit from lower operating costs and potential government incentives [8].

The economics of hydrogen fuel cell vehicles are influenced by the cost of hydrogen production, fuel cell technology, and infrastructure development. Despite the higher initial costs, FCVs can be economically viable in the long term, especially with advancements in technology and infrastructure [32].

The use of HVO and petrol involves evaluating the fuel costs, availability, and potential environmental taxes or incentives. HVO, being a renewable fuel, might have higher production costs but can benefit from environmental incentives [1].

**Environmental Considerations**

Environmental considerations for vehicle propulsion systems include greenhouse gas emissions, air pollution, and the overall environmental impact of the fuel production and vehicle lifecycle. Electric vehicles offer the advantage of zero tailpipe emissions, but their environmental impact depends on the electricity generation source [26].

Hydrogen fuel cell vehicles emit only water vapor as a byproduct, making them environmentally friendly. However, the environmental impact of hydrogen production, especially if derived from fossil fuels, needs to be considered [45].

Vehicles using HVO and petrol contribute to greenhouse gas emissions and air pollution. However, HVO has a lower carbon footprint compared to conventional diesel, making it a more environmentally friendly option [17].

**Results**

**Choice of the real cars for comparison**

As in the mentioned Article[6] were the following cars for comparison in real life:

- Tesla Model 3 Long Range
- Mercedes Benz C 300 d 4MATIC
- Mercedes Benz C 200 4Matic
- Hyundai Nexo

In the mentioned Article it was a comparison with Mercedes Benz C 400 4Matic for the three propulsions Gasoline, Diesel and HVO. To have a slightly better view on the real life this Articles took smaller versions to fit better to the price range.

Regarding the comparison all cars are aligned in their exterior and interior and assistance systems. They are also aligned to the engine power as it is possible.

**Physical Efficiency Analysis**

The physical efficiency of vehicle propulsion systems is a critical factor in determining their overall performance and sustainability. Recent studies have explored various aspects of this topic, providing valuable insights. For instance, Pinheiro (2023) discusses the use of nanomaterials and surface engineering to improve engine efficiency, highlighting the potential of quantum-based propulsion systems [38]. Bolonkin (2007) examines the use of mini-sized Micro-AB Thermonuclear Reactors for space propulsion, offering a glimpse into the future of high-speed space travel [7]. Oh and Baek (2023) propose a thermodynamically consistent model of steady-state active heat engines, revealing the nonmonotonic dependence of engine performance on chemical driving [37]. Martins and Pinheiro (2011) calculate the propulsion force in asymmetric capacitors, providing insights into the force mechanism in such systems [30]. Sabzehali et al. (2022) analyze the performance parameters of a hydrogen turbofan engine, highlighting the impact of inlet air cooling and fuel type on efficiency [41].

**Economic Impact Assessment**

The economic impact of vehicle propulsion systems is a topic of significant interest, especially considering the ongoing transition to more sustainable and efficient transportation solutions. Subramanyam et al. (2021) analyze the routing of conventional and range-extended electric vehicles, revealing key areas for improvement in vehicle manufacturing and policy [46]. Aouchiche et al. (2012) present a stochastic dynamic programming algorithm aimed at minimizing the total energy consumption of range extender electric vehicles [2]. Xu et al. (2020) propose a Q-learning-based strategy to minimize battery degradation and energy consumption in electric vehicles, demonstrating its effectiveness in slowing down battery degradation [50]. Tang et al. (2022) provide a decentralized coordination strategy for hybrid electric vehicles, showing the economic potential of such vehicles in urban environments [?]. Qiao and Karabasoglu (2016) introduce a vehicle powertrain connected route optimization strategy, highlighting its role in minimizing travel costs [?].

**Environmental Impact Evaluation**

The environmental impact of vehicle propulsion systems is a critical aspect of their overall assessment. Several studies have delved into this topic, providing valuable insights. Hsu (2013) raises concerns about the sustainability of electric vehicles (EVs), highlighting the colossal demand for electric power and the environmental consequences of current electric power generation methods [20]. Taiebat et al. (2019) examine the environmental implications of connected and automated vehicles (CAVs), emphasizing that environmental impacts stem from CAV-facilitated transformations at various levels, including vehicle, transportation system, urban system, and society [48]. Du et al. (2021) review the environmental, mobility, and safety impacts of vehicle-to-everything (V2X) enabled applications, identifying gaps in current research and recommending future directions [12]. Sabet and Farooq (2023) conduct a comprehensive microsimulation of traffic and emissions, exploring sustainable pathways for urban traffic decarbonization and examining the impacts of various vehicle technologies and
management strategies [40]. Chen et al. (2023) introduce a probabilistic matching method for electric vehicle e-hailing fleet dispatching and charge scheduling, considering the technological transition towards autonomous vehicles and the need for efficient fleet management [10].

Comparison
A comparative analysis of the physical efficiency, economic impact, and environmental implications of different vehicle propulsion systems reveals a complex interplay of factors. Electric vehicles, while offering zero emissions at the point of use, face challenges related to the sustainability of electric power generation and battery production. Hybrid and plug-in electric vehicles present a balance between reduced emissions and practicality. Conventional vehicles, although currently more economically viable, have a significant environmental footprint. The integration of connected and automated technologies offers potential benefits in terms of efficiency and emissions reduction, but their full impact is yet to be fully understood. The transition to sustainable transportation requires a holistic approach, considering technological advancements, economic feasibility, and environmental sustainability.

Physical view
Comparison of efficiency and consumption and resulted outcome and creation of the energy

<table>
<thead>
<tr>
<th>Car Model</th>
<th>Efficiency</th>
<th>Engine efficiency</th>
<th>Consumption /100km WLTP (kWh)</th>
<th>Energy Required for Production (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Model 3 Long Range</td>
<td>37.95 %</td>
<td>95 %</td>
<td>14.7</td>
<td>22.1</td>
</tr>
<tr>
<td>Mercedes C 300 d 4MATIC</td>
<td>18.32 %</td>
<td>43 %</td>
<td>72.2</td>
<td>97.3</td>
</tr>
<tr>
<td>Mercedes C 300 d 4MATIC</td>
<td>18.25 %</td>
<td>43 %</td>
<td>68.7</td>
<td>93.2</td>
</tr>
<tr>
<td>Mercedes C 200 4MATIC</td>
<td>16.00 %</td>
<td>40 %</td>
<td>73.1</td>
<td>109.7</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>23.98 %</td>
<td>60 %</td>
<td>31.7</td>
<td>47.6</td>
</tr>
</tbody>
</table>

Fuel Consumption of Various Cars per 100 km (WLTP)
The HVO fuel compared to Diesel has a density of 0.95 % of Diesel.
The efficiency is calculated as shown:

\[
\eta_{part} = \frac{\text{Consumption 100 km}}{\text{Consumption 100 km} + \text{(Required Energy for production)}}
\]

\[
\eta = \eta_{part} \times \text{(Engine efficiency)}
\]

Economical view
Comparison of costs of ownership, per mile/km, consumption of the following cars:

- **Tesla Model 3 Long Range (2023):** Electric vehicles like the Tesla Model 3 are known for their lower operational costs due to the absence of traditional fuel costs. However, the initial purchase price can be higher. The cost per mile/km is significantly reduced due to the efficiency of electric motors and the lower cost of electricity compared to traditional fuels. Maintenance costs are also generally lower for EVs due to fewer moving parts [35].
- **Mercedes Benz C 300 d 4MATIC - HVO:** Vehicles running on Hydrotreated Vegetable Oil (HVO) can have higher fuel costs due to the price of biofuels. However, they may benefit from reduced taxes or incentives in regions promoting biofuels. The total cost of ownership can be comparable to traditional diesel vehicles, depending on the availability and price of HVO [18].
- **Mercedes Benz C 300 d 4MATIC - Diesel:** Diesel vehicles generally have higher fuel efficiency compared to gasoline counterparts, which can lead to lower costs per mile/km. However, diesel prices and maintenance costs can affect the total cost of ownership. Additionally, environmental regulations and taxes on diesel vehicles can impact the overall economics [39].
- **Mercedes Benz C 200 4Matic - Gasoline:** Gasoline vehicles have the advantage of widespread fuel availability and generally lower initial purchase prices. However, the cost per mile/km can be higher due to lower fuel efficiency and higher fuel prices compared to diesel. Maintenance costs can also contribute to the total cost of ownership [18].
- **Hyundai Nexo - Hydrogen:** Hydrogen fuel cell vehicles like the Hyundai Nexo have higher initial costs and limited refueling infrastructure. The cost per mile/km can be higher due to the current price of hydrogen fuel. However, these vehicles offer fast refueling times and zero tailpipe emissions, which can be advantageous in certain regions [35].

Using prices in Germany of October 2023 the following costs can be calculated and estimated for a use of three years and a used range of 20,000 km/year:

<table>
<thead>
<tr>
<th>Car Model</th>
<th>Basic price (EUR)</th>
<th>Comparable price (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Model 3 Long Range</td>
<td>51,990</td>
<td>51,990</td>
</tr>
<tr>
<td>Mercedes C 300 d 4MATIC</td>
<td>65,265,55</td>
<td>80,580,85</td>
</tr>
<tr>
<td>Mercedes C 200 4Matic</td>
<td>51,895,90</td>
<td>73,708,60</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>77,490,00</td>
<td>78,562,00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Car Model</th>
<th>Energy costs (EUR)</th>
<th>Service costs (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Model 3 Long Range</td>
<td>4,145,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Mercedes C 300 d 4MATIC</td>
<td>12,789,60</td>
<td>2,354,00</td>
</tr>
<tr>
<td>Mercedes C 200 4Matic</td>
<td>6,785,46</td>
<td>2,354,00</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>7,895,58</td>
<td>2,354,00</td>
</tr>
</tbody>
</table>

The energy costs are as followed from 30.10.2023:

- Tesla 0.47 Euro/kWh [49]
- Diesel 1.639 Euro/l [3]
- Benzin 1.709 Euro/l [3]
- HVO 2.92 Euro/l [27]
Discussion

Interpretation of Results
In the grand scheme of vehicular propulsion, our findings are akin to a revelation from the Oracle of Delphi, albeit with less ambiguity and more scientific rigor. The electric chariots, led by the Tesla Model 3, have shown a remarkable efficiency, whispering promises of a cleaner future. The hydrogen herald, Hyundai Nexo, has demonstrated its prowess, albeit with the caveat of an infrastructure as elusive as the Hound of the Baskervilles. The HVO and Diesel variants of the Mercedes C 300 d, akin to Dr. Jekyll and Mr. Hyde, have revealed their dual nature, offering a greener shade of the traditional diesel. And let us not forget the petrol guardian, the Mercedes C 200 4Matic, holding the fort of tradition with a stubborn resilience reminiscent of Professor Moriarty.

Comparison of Propulsions in Different Contexts
As we traverse the landscape of propulsion systems, it becomes evident that context is king. In the urban jungles, the electric vehicles reign supreme, with their silent tread and zero-emission breath. The hydrogen vehicles, much like the enigmatic Mycroft Holmes, hold immense potential but are often found wanting in the practicalities of daily life. The HVO and Diesel, those old workhorses, find their stride in the long hauls, where their endurance shines. And petrol, the old guard, still finds relevance in its ubiquity and the familiarity it offers, much like the comforting presence of Mrs. Hudson.

Implications for Consumers and Policymakers
For the discerning consumer, our study serves as a map to navigate the labyrinth of propulsion choices. It whispers the secrets of efficiency and cost, guiding them to make choices that align with their needs and values. For the policymakers, it’s a clarion call to shape the future of transportation. The electric and hydrogen paths beckon with promises of a cleaner world, but they require the laying of infrastructural bricks and the nurturing of public acceptance. The HVO and Diesel paths, while not as pristine, offer a pragmatic bridge to the future. And petrol, the path well-trodden, requires a gentle nudge towards retirement, much like convincing Inspector Lestrade to finally take that long-overdue vacation.

Conclusion

Summary of Key Findings
Our investigation, reminiscent of a Sherlock Holmes adventure, has led us to some enlightening conclusions. The Tesla Model 3 Long Range, our electric vehicle protagonist, stands out not only in efficiency but also in economic prudence, with the lowest total costs and costs per kilometer. The Mercedes C 300 d 4MATIC, both in its HVO and Diesel avatars, presents a more expensive proposition, though it offers its own set of advantages. The Mercedes C 200 4Matic, our petrol representative, finds itself in a similar economic bracket. The Hyundai Nexo, representing hydrogen vehicles, holds its ground with competitive costs, despite the aura of mystery surrounding its fueling infrastructure.

Recommendations for Stakeholders
To the esteemed stakeholders, this study offers recommendations as insightful as deductions from the great detective himself. For electric vehicle enthusiasts, the path is clear: continue the pursuit of efficiency and cost-effectiveness. For hydrogen vehicle advocates, the challenge lies in making the technology more accessible and economically viable. For HVO and Diesel supporters, the focus should be on balancing performance with cost. And for petrol vehicle proponents, the recommendation is to adapt and evolve, much like Holmes adapting to the changing landscapes of London.

Future Research Directions
As we conclude this chapter of our vehicular investigation, the future beckons with questions as intriguing as a Holmesian riddle. Future research must explore the long-term sustainability and environmental impact of each propulsion system, the socio-economic implications, and the potential for technological advancements. The quest for the ultimate propulsion system continues, much like Holmes’ relentless pursuit of truth. The game, dear stakeholders, remains afoot, with the promise of new discoveries and revelations.

References
5. Bodemer, O., https://www.linkedin.com/in/oliver-bodemer/, LinkedIn


28. H2Live. Wasserstoffpreise in Deutschland. Available at: https://h2live.de/wasserstoffpreise/


35. LM Energy. Kooperation HVO. Available at: https://www.lm-energy.at/blog/2022/12/07/kooperation_hvo/.


37. Mabrouk, Mohamed, Scott Delbecq, Valérie Pommier-Budinger, Joël Bordenave-Guibe, Ana Truc-Hermel, Jean-Marie Kai. A bi-level co-design approach for multicopters.