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Research Article

Towards Carbon-Free Automotive Futures: Leveraging AI And ML For Sustainable Transformation

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ARTICLE INFO **ABSTRACT**

This paper delves into the transformative role of artificial intelligence (AI) and machine learning (ML) in reshaping the automotive industry towards sustainability and environmental consciousness. It begins by examining the integration of intelligent infrastructure, such as sensor-equipped traffic signal lights and cameras, aimed at enhancing road safety and efficiency. Furthermore, the development of autonomous driving and connected vehicle technologies, in conjunction with advancements in V2X communication and 5G technology, presents promising avenues for reducing energy consumption and CO2 emissions in transportation. A critical analysis of the current state of carbon emissions in the automotive industry underscores the pressing need to transition towards carbon-free alternatives, with AI and ML identified as essential tools for predicting emissions, optimizing energy demand, managing electric vehicles, and implementing eco-driving strategies to achieve zero-carbon emissions. Additionally, the paper explores various AI/ML applications for vehicle efficiency improvement, battery optimization, electric vehicle charging, and intelligent traffic management, highlighting their contributions to emissions reduction and improved traffic flow. Nonetheless, the integration of AI/ML into carbon-free automotive futures poses challenges such as regulatory hurdles, infrastructure development, and ethical considerations. Despite these challenges, AI and ML offer promising solutions to mitigate climate change and drive towards a sustainable automotive industry.

Keywords: Automotive Industry, Carbon Emissions, Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Smart Manufacturing (SM) , Zero Carbon,

1. Introduction

The public road infrastructure has introduced various intelligent equipment to ensure the safety and efficiency of the road network. For instance, the intelligent traffic signal light can change the signal time according to the vehicle traffic by equipping it with sensors. Furthermore, the intelligent traffic camera can identify the behavior of the vehicles and detect whether there are accidents that need human intervention. In 2018, the Transportation Research Board, the National Academy of Engineering, and the Federal Highway Administration cooperatively organized the Automated Vehicle Symposium, including the International Conference on Connected Vehicles and the Automated Vehicle Symposium.

Fig 1. **Carbon-free environment.**

The International Intelligent Vehicles Symposium emphasizes the importance of sustainable transportation and innovative technologies, such as the Internet of Things, artificial intelligence, and machine learning, to reduce energy consumption during vehicle operation [1]. Automated vehicles can communicate and share their driving and operation information through V2X (Vehicle-to-Everything) communication or 5G technology. In that case, cooperative automated vehicles can further save energy and reduce CO2 emissions in the transportation industry.

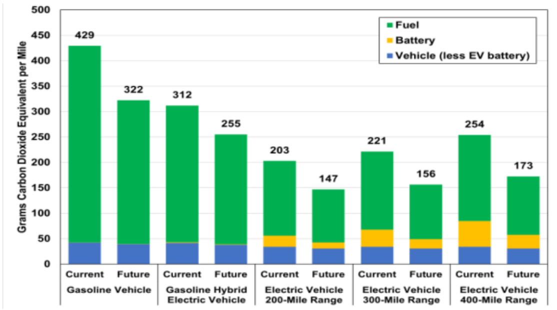

Fig 2. **Vehicle Emissions - Fuel vs Battery**

The development of autonomous driving and pro-environmental operation is a crucial means to solve problems such as road congestion, safety, and environmental pollution, and has become the development trend of modern automobiles. Although autonomous driving has been developed for many years, car automatic parking, adaptive cruise, and other functions have been universally carried out; the single-car intelligent cruise has developed well. However, the rapid development of connected vehicle technology provides the possibility to extend the research of vehicle driving behavior control from a single car to multiple cars. The collaboration of vehicles based on wireless connection can significantly reduce the collision probability and improve overall traffic efficiency. Moreover, the emergence of 5G technology and artificial intelligence, big data, and other technologies can realize the interconnection of vehicles and control the behaviors of connected vehicles. Researchers have designed various connected vehicle collaborative control strategies based on linear and nonlinear vehicle models, optimal control, and game theory, which can be divided into online and feedback control.

2. Current State of Carbon Emissions in the Automotive Industry

The world is experiencing a climate crisis caused by artificial carbon emissions [2]. The emissions create a greenhouse effect that warms the Earth, causes ice to melt, and drives stronger and more frequent natural disasters like hurricanes, floods, and wildfires. The transportation sector, primarily cars and trucks, is responsible for about a quarter of all the world's CO2 emissions; experts estimate that the transportation sector is also one of the fastest-growing sources of carbon emissions [3].

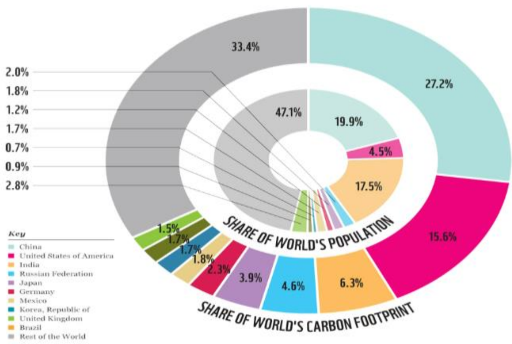

Fig 3. **Global Carbon footprint.**

This exploding growth stubbornly persists in developed and developing nations around the globe, where the world is home to 1.4B cars and light-duty trucks. This number could double by 2035, almost completing global saturation. However, the scientific consensus is clear: the world must eliminate carbon emissions by 2050 to keep the Earth from warming 2 degrees Celsius and slipping into dangerous, irreversible climate change. Every year, as driving continues to grow, global society must take aggressive, carbon-intensive solutions like manufacturing new electric vehicles and building out electric vehicle charging infrastructure that furthers the world from the climate change tipping point. Even if electric vehicles - or a new technology that's not yet on the market - managed to eliminate vehicle tailpipe emissions tomorrow, the overall carbon emissions are still on an upswing commensurate with the growth of vehicle miles driven globally.

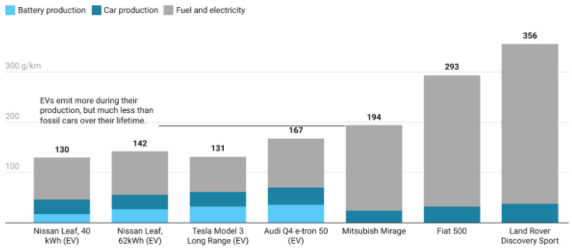

Fig 4. **Emission of EV cars vs regular fuel cars**

That uptrend signals an inexorable and unsustainable climb in carbon emissions. The auto and technology industries need to invest in expanding renewable energy, including solar, wind, and energy storage plants so that the industry can continue to grow. The world cannot begin down one pathway without the other. Whether or not the world begins this transformation lies partly with the outcome of machine learning, also called artificial intelligence, or ML/AI. *Machine learning* is a technique in which a platform trains itself to understand complex patterns using vast amounts of training data and sophisticated statistical code to make predictions or identify anomalies with whatever new data the machine encounters. A.I.
On the other hand, A.I. is a technique capable of improving machine learning functions at will without waiting for a human being to fine-tune the mathematical code and data.

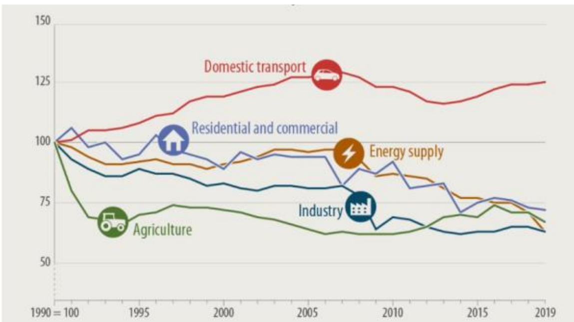

Fig 5. **Emissions with various types**

Some scientists, technologists, and industry leaders believe that ML/AI is poised to expand exponentially, making the world's roadways increasingly smarter, safer, and cheaper. These are vital ingredients in revolutionizing the car-based transit industry and pulling away from the tipping point of a dangerous climate change. Others remain more skeptical and see a future with roadways just as crowded with single-occupant automobiles, carbon emissions, and dangerous climate change. ML/AI's role in this environmental catastrophe becomes exponentially more daunting when we consider the potential industrial gains that ML/AI has pried open to automakers and technology giants by analyzing driving data on the world's major roads. Vehicle sensor data is already being sold to retailers, insurers, law enforcement, city agencies, and the highest bidder. Every company sees their investments in ML/AI as crucial to beat out their corporate competitors and create a bigger slice of what could become the world's largest-ever business.

3. Role of Artificial Intelligence (A.I.) and Machine Learning (ML) in Carbon Reduction

Several machine learning models are used to predict actual/existing harmful emissions and associated harmful pollutants like CO2, NOX, particulate matter (PM), hydrocarbons, carbon monoxide (C.O.), etc., in real-time under Real Driving Emissions (RDE) driving conditions. On-RDE emission NO detection models are performed using Gaussian Process Regression (GPR) and other respiratory machine learning models. The ML regression models are developed to predict the emission count rate of PM using real-time data [4].

Fig 6. **AI will control the Emissions.**

Battery technology research development and improvements in electric, electric powertrain electrification, and high battery power density are critical steps toward the electrification of the transportation sector for a carbon-free automotive future. Data analytics-based digital twin techniques and ML algorithms are utilized for design and development, electrical/thermal management, and battery safety. The reliability and aging of batteries are enhanced using AI/ML algorithms. Deep learning models are developed for action learning powertrain optimization strategies. Machine learning models are built on road and on-engine testing, simulation, and dynamometer testing. Machine learning-based online optimization techniques and predictive energy management solutions are developed for HEV and PHEV energy systems to reduce greenhouse gas emissions in automotive. The AI-based eco-driving strategies and methods are studied using ML techniques to achieve zero-carbon emissions in the automotive transportation sector.

Artificial intelligence (A.I.) and Machine Learning (ML) play significant roles in carbon reduction strategies in various industrial sectors, including automotive [1]. Advanced ML models and techniques are developed for energy demand prediction; traffic prediction, optimization, and automation; electric vehicle (E.V.) load prediction, profiling, and management; E.V. charging/discharging optimization; smart energy management systems; greenhouse gas (GHG) (including CO_2) emission estimation; real driving emission (RDE) prediction; eco-Autonomous Vehicles; green supply chain transportation; and logistics vehicle routing and assignment. In this chapter, the authors discuss the role of AI/ML in carbon mitigation in automobiles.

4. AI/ML Applications for Vehicle Efficiency Improvement

The improvements to the battery technology are another area that is ripe for the ML application. Several companies and initiatives have sprung up worldwide, explicitly aiming to conduct AI-empowered design and search for tracks down and craft novel materials with excellent electrochemical properties. Although already in use, most presently available electric vehicles use lithium charging equipment with aftermarket chargers upon completion. In a stream, ML can confirm demand levels. Some supermarkets and small-format dealers equip 50-kW chargers at their locations, and some drivers shop at these sites while waiting. Some of the biggest logistics businesses, such as Amazon, now depend on E.V.s, which add a layer of drivers between the vehicle's automation and A.I. functions. Wind or photovoltaic solar power generation in more railroad-type sports is growing with ML-based predictions of uncertain output streams [4].

ML has the potential to identify the weight reductions in safety systems in the design of vehicles, and it has been implemented for crucial subsystems and components of vehicles such as tires, brakes, gears, transmission, and even critical parts made by metal additive manufacturing. Additional weight will impact performance and safety, but all components' 10% weight reduction leads to the equivalent gasoline efficiency. This work entails energy use and CO_2 emissions, among many others. ML helps to identify the optimum for numerous parameters in complex systems that can be described by hundreds if not thousands of control pressures. Finally, ML excludes the orders of magnitude levels of local optima. In particular, it has been shown to have rigor efficiency-related characteristics for batteries in electric powertrains [5].

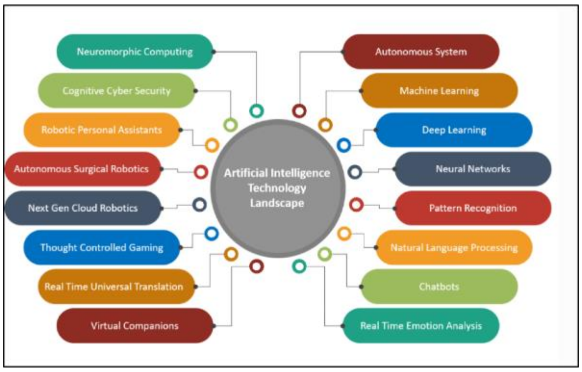

Fig 7.**AI ML Areas in Vehicles**

Vehicle efficiency improvements offer over 70% of all short- and medium-term emissions reductions in passenger cars. AI/ML can tackle this problem in myriad ways, with practical applications already ongoing. A.I. with data science can forecast energy use for a given route and traffic conditions [6]. ML learns usage patterns to optimize the power delivery of legacy or current models.

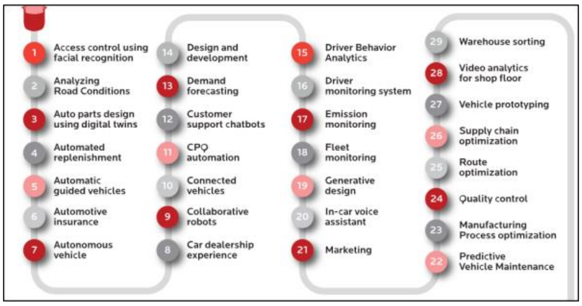

Fig 8. **AI Use Cases in Vehicles.**

The new models, where ML has an advantage over other optimization techniques, including the optimal control theory, do not require detailed dynamics knowledge and still can deliver significant benefits. ML can also study the recharge behavior. It applies long short-term memory neural networks and stochastic optimization techniques to predict the E.V.'s future movement and homecoming time, which gives a recharge recommendation. ML improves efficiency in physics-based models and computer simulation, which is dominant in vehicle development, although this impact is beginning to materialize in this writing. However, how much of these potential benefits will be taken by the developers of competing vehicles, unless forced to do so by regulation, is a giant, open question.

5. AI/ML Applications for Intelligent Traffic Management

AI/ML has found various applications that contribute to intelligent traffic management, such as accelerated traffic data analysis, risk management, and impact forecasting. Well-known AI/ML models are being used to predict traffic scenarios, optimize traffic control, and control traffic if it is a self-driving vehicle. With the commercial maturity of commercial products and the realistic expectation that there will soon be a single SAE level 4 autonomous vehicle on the market that is capable of highway driving, the focus of research has shifted to scenarios involving multiple autonomous vehicles. There are use cases that were impractical for human drivers, even with the help of traffic lights or roundabouts.

Fig 9. **AI/ML - Intelligent Traffic Management**

Traffic optimization in urban environments always includes positioning and progress control, optimal traffic light signal generation, etc, depending on traffic densities. There are strategies like minimum time intersection crossing for one autonomous vehicle allowed at a time after all human-driven vehicles are cleared.
Traffic and urban mobility pose serious challenges today worldwide, concerning human lives, time lost, and environmental stresses [7]. The global epidemic of traffic accidents results in significant fatalities and disabilities and millions of U.S. Dollars in costs for treating injuries. With a burgeoning population and a quest for a more comfortable life, congestion in cities has taken a worse shape in the twenty-first century [8]. One of the key promises of AI-based self-driving vehicles is the potential to dramatically reduce these derived costs.

6. AI/ML Applications for Battery Optimization and Electric Vehicle (E.V.) Charging

The research community has turned to machine learning (ML) and artificial intelligence (AI) to address the above-mentioned challenges [9]. Mainly AI is widely used for battery optimization in two main categories: (i) materials discovery and design and (ii) battery management systems. In the first category, AI/ML has been applied to discover advanced compounds with targeted electrochemical properties.

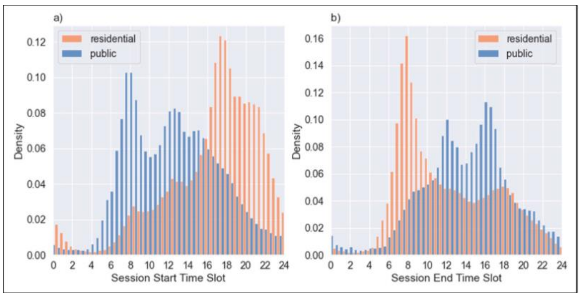

Fig 10. **Charging Event Counts.**

These materials mainly include cathodes and anodes, solid-state electrolytes, and electrolyte additives, which are crucial for the ongoing development and optimization of lithium-metal batteries (LMBs), high-voltage cathodes, and other advanced battery chemistries. Research in the second category mainly focuses on accurately predicting battery degradation under various operational conditions, i.e., lithium plating, voltage fade, and capacity fade, using all available battery data.

Charging Type	Charge from–to level	Charging time	
		16kWh	100kWh
Level 1 2.4kW	20%–100%	5 hours	33 hours
Level 2 7.2kW (1-phase)	20%–100%	2 hours	11 hours
Level 2 21.6kW (3-phase)	20%–100%	36 minutes	3.7 hours
DC 50kW	20%–80%	12 minutes	1.2 hours
DC 150kW	20%–80%	4 minutes	24 minutes
DC 450kW	20%–80%	1.3 minutes	8 minutes

Table 2. **Charging value changes with Battery capacity.**

Supply chain development and supportive policies may substantially reduce battery prices and the cost of electrified vehicles. Electrified transportation can also deliver other benefits, including improved air quality, fewer greenhouse gas (GHG) emissions resulting from the production, transport, and use of petroleum-based fuels, decreased exposure to volatile petroleum prices, and reduced maintenance costs [12,18]. Existing technology can deliver vehicles that meet a wide range of consumers' needs, including those who engage in extensive highway driving and heavy-duty, off-road, and specialty vehicle users. Advances are occurring in batteries, grid integration with vehicle charging, and supply chain development.
Electrification and decarbonization are essential for a sustainable future. Historically, light-duty and medium- and heavy-duty trucks have been propelled by internal combustion engines powered by petroleum-derived fuels. In 2016, the transportation sector accounted for 69% of U.S. petroleum consumption and 29% of U.S. carbon dioxide (CO2) emissions [4]. Alternative approaches for reducing petroleum consumption and transportation emissions include hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and electrifying buses, trucks, and non-road vehicles.

7. Challenges and Limitations of AI/ML in Carbon-Free Automotive Futures

Of course, as always, exactly how artificial intelligence, machine learning, and data science will find their way into solving such problems is unclear. Already, researchers are creating monolithic, intelligent systems that incorporate all the needed components, from data analysis to decision-making. In contrast, others focus on each component or WBS of such systems and create stand-alone, modular tools that can be plugged in or removed. Some, for example, have focused on developing new anomaly detection techniques that are, in turn, used within an automotive autonomous or electric vehicle maintenance or monitoring and control dashboard. Analysis of the battery performance with various vehicle types. (Test data collected from Kaggle data sets).

	Model	Brand	Efficiency_WhKm
84	EQV 300 Long	Mercedes	273
90	e-tron S 55 quattro	Audi	270
33	Cybertruck Tri Motor	Tesla	267
67	Cybertruck Dual Motor	Tesla	261
99	e-tron S Sportback 55 quattro	Audi	258

Fig 11. **Analysis of the different types of vehicles.**

AI and ML are likely in every aspect of modern life and industry, including the auto sector. Accordingly, it is no surprise that they are being used to further the aims of carbon-free vehicle futures. However, it should be noted that the problems such futures face have substantial machine learning components [13]. To begin with, the problem of electric vehicles (E.V.s) being a global one means over a billion vehicles must be integrated one by one into every nation's electrical grid schedule, which will be accomplished only via deep learning (DL). Second, these vehicles must be integrated individually into models for weather forecasting, which is also done using DL. Managing the distribution of E.V.s and managing their battery effectively and efficiently are challenges requiring anomaly detection, which is, in turn, a component of DL. A.I. and ML techniques are excellent tools for handling carbon-free automotive futures.
Carbon-free automotive futures are a challenging, complex, and multifaceted area for examination [10]. To that end, this subsection necessarily limits itself to discussing just a few of the most critical challenges and complexities that law, regulation, and industry must hammer out and resolve to pursue environmentally friendly auto-making. These challenges include, but are not limited to, air quality, environmental impact, worker rights, and the human rights of both consumers and workers [15].

8. Ethical Considerations in AI/ML Implementation for Carbon Reduction

The ethical considerations in AI/ML implementation for carbon reduction are two-pronged: 1) the potential for A.I. and ML models to propagate existing climate injustices and biases, the risk of which is particularly exacerbated when implemented to affect existing practices and 2) the broader ethical considerations around introducing AI/ML driven solutions to complex problems with potentially far-reaching consequences. Consequently, it is necessary to approach the implementation of AI/ML in the automotive sector with care and consider how to take steps to mitigate these unmitigated risks [11,17].

Fig 12. **Ethical considerations in Carbon Zero strategy.**

This might include using diverse datasets in training, carefully interrogating the output, and including steps to mitigate or rectify the impact of automating a traditionally manual process in a product (simplify). To ensure the overall negative impact of an A.I./ML-driven process does not harm humans or nature, other things, a well-trained ethicist, practitioners skilled in the methods and applications of ethics in practice, should engage in and work through the impacts of a particular AI/ML product launch, defining what measures for impact

reduction or prevention should be included and then further niche writings on specific facets for development[18].
The introduction of AI and ML-driven models into industries such as manufacturing and automotive has introduced significant efficiencies and opportunities for innovation. This includes employing AI/ML methods to increase vehicle fuel efficiency and reduce carbon generation via predictive maintenance. However, such implementation calls for understanding the pragmatic potential, realistic limitations of ML, and the ethical constraints on the implementation they may introduce [12].

9. Case Studies: Successful Implementation of AI/ML in Carbon-Free Automotive Solutions

AI/ML can be employed to make the vehicle more innovative and efficient, ultimately leading to a carbon-free transportation industry. Namely, advances in artificial intelligence have led to new systems for guiding cars in "maps," optimizing energy management in new and complicated situations and so-called vehicle-to-x interactions, and improving and complementing the rule-based systems implemented previously. Implementing ML in the car can result in higher efficiency and fewer trips to refuel or recharge. This is done by optimizing the power consumption within environmental constraints, maximizing the time spent in the shallow emission mode such as, in the case of plug-in hybrid, driving in the all-electric mode section of the route ideally suited to recharge on E.V. in hybrid Electric Vehicle thanks to great declines associated with the execution of the maneuver [14,16]. AI-based energy optimization is a problem of managing the available electric energy so that vehicles use only electric energy and minimize toxic emissions[25,29].
The automotive industry's climate footprint accounts for 12% of total CO_2 emissions [6]. Data and machine-learning technologies can effectively reduce emissions [1]. For example, AI-based predictive maintenance can reduce the waste of materials, fuel, and exhaust by optimizing and reducing the need for preventative maintenance. AI/ML advancements can optimize the manufacturing process, from welding and riveting to the final assembly and dispatch [13]. Both digital twins of the entire vehicle and their components and machine-learning models trained in both simulated and real-life environments resulted in significant carbon and money savings on the production line. Moreover, machine learning models can inform about the expected lifetime of the automotive part, paving the way for their better design, energy efficiency, and safer transportation [17,19].

10. Policy and Regulatory Frameworks for Promoting AI/ML Adoption in the Automotive Industry

To prevent these issues from being passed down the supply chain and ensure that their ethical and legal frameworks reflect across interconnected emerging technologies, all industries should rapidly support the work of the E.U. and the US CPSC to develop a standardized regulatory framework as quickly as possible. Suppose people wait to turn their minds to these issues until the technologies are mature. In that case, the industries will find that fragmented policies have been cooked into their tech stacks- making future integrated development volume unbearable, just as the same tech becomes a lifeboat away from habitable Earth. This happens, on the other hand, when industrial input is needed to develop standards the most[21]. Getting ahead of regulation in these areas will probably develop longer-term access to green sectoral opportunities and a broader favorable zeitgeist [20].
As in the case of data regulations, the rapid proliferation of data regulations prompts the further proliferation of different regulatory interpretations about AI and autonomous vehicle technologies [14]. In addition to the above, multi-tier content update cycles (originating in technology OEMs and tier 1 suppliers to tier N suppliers) and the human resource issues resulting from the rapid escalation of digitalization within connected autonomous vehicles (CAV) and market developments bring on the need for governance updates [21].
Policy and regulatory frameworks are in place to protect the welfare of consumers and promote the widespread adoption of responsible and safe technologies.

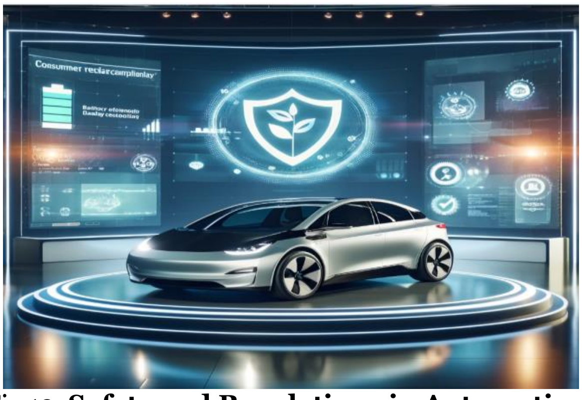

Fig 13. **Safety and Regulations in Automotives**

Policymakers and professional bodies, such as the A.I. Policy Initiative, are communicating the necessity of regulations in promoting A.I. use within the automotive industry [24,27]. Continued updates and governance are therefore crucial. However, they must be written and executed in a standardized approach. The uptake of different ethical and intellectual property frameworks has significant variations across and within jurisdictions and complicates the relationships across supply chains and digital factories. With the adoption of AI/ML technologies, hardware and software I.P.s increasingly become dependent on each other, exacerbating the problem [28].

11. Economic Implications of AI/ML in Carbon-Free Automotive Futures

Car-sharing and ride-hailing services are increasingly contributing around 30% of automotive revenue. The evolving automotive firms, traditional or modern, create new employment opportunities in various sectors by integrating a few advanced technologies. The autonomous features are being seen as a new shape of automotive production, and the driver- and vehicle-centric designs will become more customized.

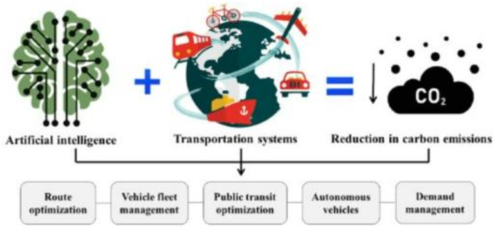

Fig 14. **AI in Carbon Emission Reduction.**

The database sector is inexplicable and more critical for analyzing the vehicle; telematics is one module in which the whole vehicle's health can be visualized, and a few vehicle-configurable factors are imperfect due to database quality and unavailability [23]. Combining this part with AI/ML gives a good predictability model for used car services' depreciation and future value. AI/ML with vehicle databases makes the automotive manufacturing service more reliable in the annuity system. With the evolving smart e-mobility in the city, automotive manufacturers have made MoUs with E.V. charging grid firms [15].

Fig 15. **Technology and Carbon Emission importance.**

Automotive companies are investing a significant amount of money in developing improved safety and fuel-economy standards with the assistance of AI/ML. Electric Vehicles (EVs) provide better energy efficiencies than traditional Internal Combustion Engine (ICE) vehicles. Automotive companies have reported that E.V.s have significantly less and negligible maintenance than ICE[28]. Depreciation is also lower for the E.V.s, which will encourage buyers to invest in the E.V.s, which will be a good incentive for the manufacturing sectors. The global trend is manufacturing more electric vehicles to promote a zero-carbon vision. AI/ML can aid in manufacturing electric vehicles more cost-efficiently and promote a cleaner driving environment. The "AutoSalon" in Brussels has shown that most of the cars are either hybrids or are being converted into complete electric vehicles[30].

The automotive sector has integrated various advanced technologies to provide a better user experience and cleaner energy applications. The seamless blend of mechanical parts and advanced data interfaces such as Advanced Driver Assistance Systems, infotainment systems, advanced energy storage systems, Vehicle-to-everything, and wireless communications systems in a vehicle provides an overall improved performance. The integration of advanced automotive safety systems requires centralized power and data management. Advanced driving features in the vehicle are implemented through a centralized controller that will continue to become powerful with the help of Machine Learning (ML) [16].

12. Future Trends and Potential Innovations in AI/ML for Carbon Reduction

In the future of urban strategies, where emission-free driving is mandatory, high voltage batteries can deliver an amount of power equivalent to the fast charger with an electric capacity of 20–30 kWh to lighten the demand for fast chargers connected to highly populated in catenary electrified inner city or metropolitan areas, for cost-effective strategies.

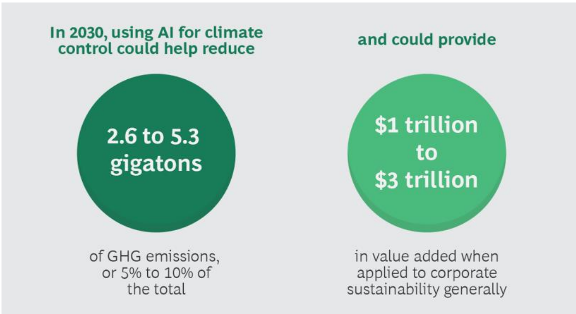

Fig 16. **Climate Control's future vision.**

The feasibility of the concept of E-cat is enriched if the grid is attacked with a high unquantifiable amount of distributed generation from storage units with photovoltaic sources in solar active day times, to absorb in the present-day grid scheme strategy more renewable transmission and distribution otherwise scheduling of controllable loads. This behavior of time series data matching might be harnessed and scheduled optimally by the usage of a machine learning (ML) platform using methods of the distance-based model ask nearest neighbors (KNN) that operate on the principle of the Euclidean distance. These similarity measures can be widely employed in different applications[12].

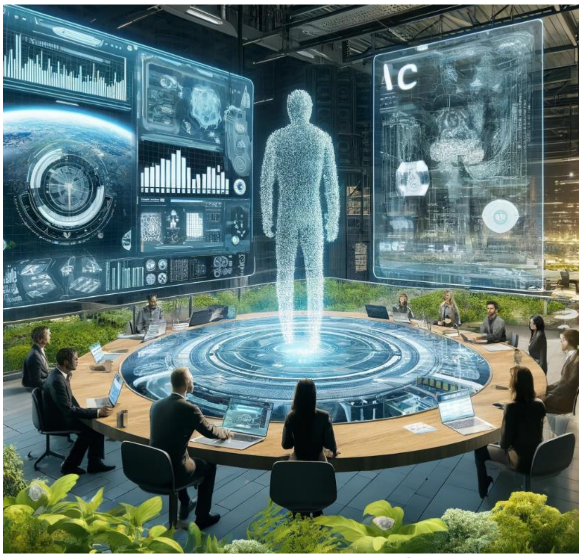

Fig 17. **Future Trends.**

Given the fast-paced introduction of power electronic converters, electric vehicles have become popular in recent years and play a significant role in carbon-free automotive futures.[17] Power electronic converters can directly amplify electric power in applications such as electrolysis for hydrogen production, and they can drive induction motors as well.[1] Along with the high-voltage batteries at the initial stage of the electric powertrain, a considerable amount of energy can be regenerated at the stage of electric braking, which highly motivates the automotive industrial vertical to optimize automotive power management and transition strategies further to absorb more renewable energy to achieve a green mobility trend. Renewable energy that provides an adulterated grid requires an innovative demand side, such as electric vehicle (E.V.) charging/discharging loads at consumer sites or electrically mobile cargo to grid (V2G) platforms and electrically mobile charging stations (V2G) from the E.V. grid at charging sites, that results into intelligent, digital, and renewable energy-based electrification of the transportation systems.

13. Collaboration and Partnerships for Accelerating AI/ML Adoption in the Automotive Sector

Electric vehicles (EVs) primarily based on batteries, are nowadays considered a priority to reduce GHG emissions from the transportation sector, where road transportation accounts for a significant portion of emissions[16]. Accurate estimating CO2eq emissions for the E.V. is considered an initial step before deciding on energy sources and technology. In this study, a data-driven methodology is proposed to estimate CO2eq emission factors for a battery electric vehicle. The estimation results confirm the potential of lifecycle-based powertrain-oriented CO2eq emission estimation [21,27].
There is a growing body of research on ML and AI applications in the automotive sector, but no systematic review articles constitute a gap or a research opportunity. A.I. and ML applications mainly include autonomous vehicles, ride-hailing, recommendation systems, emissions reduction, predictive maintenance, diagnostic systems, fault detection and system reliability, intelligent transportation management systems, traffic pattern analysis, congestion mitigation, performance management of internal combustion engines, brake health monitoring, air quality management, hazard identification, control systems, adaptive cruise control, fuel cells, and electric vehicle battery life and stability [18]. Exciting approaches related to hydrogen combustion in internal combustion engines have been found, along with bottleneck analysis in Dhaka, Bangladesh, and accident risk analysis in megacities, respectively [30].
There are academic efforts to assess AI/ML in various areas, such as supply chain [19]. This is particularly interesting regarding mobility because it is not merely a business issue but a scientific and policy issue. If we had just investment and profitability reports, it would be hard to say where AI/ML could contribute to the effects of greenhouse gas (GHG) emissions. Following some clear reports, it is possible to create an unfair expectation of an immediate revolution in emission-based AI/ML technology. This suggests a way that science can serve policy and business: to convey an understanding of where technical and non-technical innovation takes time to reach its full effect [20].

14. Societal and Environmental Benefits of AI/ML in Carbon-Free Automotive Futures

Automated vehicles Play a key role in carbon-free automotives. First, they will help cut greenhouse gas emissions (GHGs) by reducing vehicle fuel demand. Second, strategically operated A.V.s may diminish the amount of emissions generated.

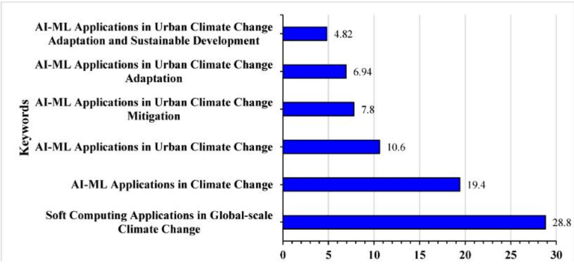

Fig 17. **Social discussions**

The driving cycle efficiency of internal combustion engines (ICEs) can be improved by continuous driver monitoring, real-time localized control inputs, and predictive driving, leading to additional environmental benefits. Suite 15.3 contains eight papers on the societal and environmental benefits of AI/ML in carbon-free automotive futures. Many of the societal benefits can be realized through regulatory approaches that steer AI/ML innovation to these ends. Using real-time data on environmental conditions and vehicle states, machine learning (ML) makes it possible to optimize energy use to reduce emissions while meeting constraints. While models are the traditional vehicle for AI, data-driven models are far more powerful and have broader applications. They allow for generalized representations of states, landscapes, and performance and can incorporate significant amounts of data, including historical and new, operation-specific data. In addition to mounting hardware expenditures, the deployment of AI/ML is often confined by the necessity for domain expertise in building models, selecting the best of many possible hardware architectures, and constructing the needed software pipelines [22,26].
An eco-driving system, an intelligent transportation system mainly designed for road transport, uses artificial intelligence (AI) to guide drive or control vehicles to optimize fuel efficiency and reduce emissions without impacting safety and travel time [21]. The Eco-driving system utilizes AI-based predictive modeling and control optimization for energy or fuel efficiency. The basic idea is to predict the vehicle's future state and environment based on real-time sensor data and determine the best control actions to minimize energy consumption [17]. These systems use various ML techniques, such as regression, neural networks (N.N.), reinforcement learning

(R.L.), etc., to create predictive models/optimization algorithms. Highway and urban networks are constructed to meet the needs of vehicles; however, they impact human beings and the environment negatively, particularly in urban areas. Congestion releases pollutants in urban street canyons, with health risks for pedestrians, residents, and staff.

Embedded and intelligent transportation systems are essential in energy efficiency and emission reduction. The vehicle system, including mechanical, electrical, and hydraulic subsystems, needs continuous monitoring for efficient and safe operation. Advanced machine learning (ML) techniques such as deep learning (DL) and anomaly detection are used to monitor data from various sensors and predict any potential mechanical issues [22]. This ML-based proactive monitoring helps repair/rectify mechanical issues before they escalate into major failures, which helps reduce energy consumption and emissions and increases safety[24].

15. Conclusion

Harnessing AI/ML for Carbon-free Automotive Futures utilizing AI/ML decarbonized strategies in automotive futures include hardware and applications in battery Management Systems (BMS) and Electric Vehicles; influencing distributions of charging stations; optimizing haptic drive cycles for long-haul road freight electric vehicles; smart grid residential demand management and V2X grid-supportive charging Roaming Services. AI/ML facilitates rapid learning with diverse data sets (synthetic with natural, high- and low-fidelity). AI/ML analyzes complex, diverse, disparate connection patterns and system changes. We published a review in Nature's open-access Journal of Computational Materials Sciences so domain specialists can engage AI/ML more effectively. AI/ML can increasingly inform super-computing, generating, and scoring ab initio reaction mechanisms. Resistances have fallen to 37 to 100 K-Cycle degradation. We continue our long-running (mission-critical, first to deliver to industry at large scale) AI/ML demonstration projects for sensory and model-based streamlining, leading to automated closure and the AI/ML-directed development of business processes. Our funded work covers 461 Patterson-deployed and –secured organizations [25]. We are permitting climate action in a high-cost, high-risk context. Upskilling and content creation generated by this work move between our other large AI/ML International R&D, collaborative, or consumer-facing projects and pilots.

The transportation sector significantly contributes to carbon and nitrogen emissions [6]. Numerous stakeholders, including industry, policymakers, and investors, are executing various strategies to mitigate these emissions. Rapid advances in electric vehicle technology have occurred over the last twenty years, and a host of A.I./ML-related projects are driving Australia toward a decarbonized automotive future. Our work with the Centre for Engineered Energy Systems (CEES) has positioned us well to begin transitioning to these technologies [4]. We also use AI/ML to characterize transport energy infrastructure prosumers, paving the way for decarbonized road transport. Of thirty worldwide ATA distribution grid projects, we have informed or deployed AI/ML on five to eight, for distributed, Internet-of-Things (IoT) managed infrastructure[21].

16. References

[1] L. Xie, T. Huang, X. Zheng, Y. Liu et al., "Energy system digitization in the era of AI: A three-layered approach toward carbon neutrality," 2022. DOI: 10.1109/ACCESS.2022.3126639

[2] J. Cowls, A. Tsamados, M. Taddeo, and L. Floridi, "The AI gambit: leveraging artificial intelligence to combat climate change—opportunities, challenges, and recommendations," 2021. DOI: 10.1007/978-3-030-01947-2_5

[3] Mandala, V. (2024). Predictive Failure Analytics in Critical Automotive Applications: Enhancing Reliability and Safety through Advanced AI Techniques. Journal of Artificial Intelligence and Big Data, 48-60.

[4] T. Lombardo, M. Duquesnoy, H. El-Bouysidy, F. Årén et al., "Artificial Intelligence Applied to Battery Research: Hype or Reality?," 2021. DOI: 10.3389/fenrg.2021.648872

[5] H. Delseny, C. Gabreau, A. Gauffriau, B. Beaudouin et al., "White Paper Machine Learning in Certified Systems," 2021.

[6] M. Hofmann, F. Neukart, and T. Bäck, "Artificial Intelligence and Data Science in the Automotive Industry," 2017.

[7] Z. Ryan Shi, C. Wang, and F. Fang, "Artificial Intelligence for Social Good: A Survey," 2020. DOI: 10.1016/j.ins.2019.11.039

[8] J. Manuel Lozano Domínguez, F. Al-Tam, T. de J. Mateo Sanguino, and N. Correia, "Analysis of Machine Learning Techniques Applied to Sensory Detection of Vehicles in Intelligent Crosswalks," 2020. DOI: 10.1007/s42498-020-00020-x

[9] Mandala, V., Premkumar, C. D., Nivitha, K., & Kumar, R. S. (2022). Machine Learning Techniques and Big Data Tools in Design and Manufacturing. In Big Data Analytics in Smart Manufacturing (pp. 149-169). Chapman and Hall/CRC

[10] A. Jaber, S. Sattarpanah Karganroudi, M. Saleh Meiabadi, A. Aminzadeh et al., "On Smart Geometric Non-Destructive Evaluation: Inspection Methods, Overview, and Challenges," 2022. DOI: 10.3390/coatings12101225

[11] M. L. Heacock, A. R. Lopez, S. M. Amolegbe, D. J. Carlin et al., "Enhancing Data Integration, Interoperability, and Reuse to Address Complex and Emerging Environmental Health Problems," 2022. DOI: 10.3390/jpm12030183
[12] Mandala, V. Towards a Resilient Automotive Industry: AI-Driven Strategies for Predictive Maintenance and Supply Chain Optimization.
[13] S. Paiva, M. Abdul Ahad, G. Tripathi, N. Feroz et al., "Enabling Technologies for Urban Smart Mobility: Recent Trends, Opportunities and Challenges," 2021. DOI: 10.1016/j.trpro.2021.03.012
[14] V. Kabir Veitas and S. Delaere, "In-vehicle data recording, storage and access management in autonomous vehicles," 2018. DOI: 10.1007/s42044-018-0009-9
[15] J. Chatterjee and N. Dethlefs, "Facilitating a smoother transition to renewable energy with AI," 2022. DOI: 10.1016/j.trd.2021.102812
[16] S. Han, Y. He, and Y. Ding, "Enable an Open Software Defined Mobility Ecosystem through VEC-OF," 2020.
[17] F. Czerwinski, "Current Trends in Automotive Lightweighting Strategies and Materials," 2021. DOI: 10.1016/j.matdes.2020.109149
[18] A. Scriven, D. Jacob Kedziora, K. Musial, and B. Gabrys, "The Technological Emergence of AutoML: A Survey of Performant Software and Applications in the Context of Industry," 2022.
[19] J. Rana and Y. Daultani, "Mapping the Role and Impact of Artificial Intelligence and Machine Learning Applications in Supply Chain Digital Transformation: A Bibliometric Analysis," 2022. DOI: 10.1016/j.indmarman.2022.09.010
[20] D. Rolnick, P. L. Donti, L. H. Kaack, K. Kochanski et al., "Tackling Climate Change with Machine Learning," 2019. DOI: 10.1016/j.joule.2019.08.009
[21] N. Tsolakis, R. Schumacher, M. Dora, and M. Kumar, "Artificial intelligence and blockchain implementation in supply chains: a pathway to sustainability and data monetisation?," 2022. DOI: 10.1016/j.compind.2021.103920
[22] T. Tung Khuat, D. Jacob Kedziora, and B. Gabrys, "The Roles and Modes of Human Interactions with Automated Machine Learning Systems," 2022.
[23] Aldoseri A, Al-Khalifa KN, Hamouda AM. Re-Thinking Data Strategy and Integration for Artificial Intelligence: Concepts, Opportunities, and Challenges. Applied Sciences. 2023; 13(12):7082. https://doi.org/10.3390/app13127082
[24] Srivastava, A.; Maity, R. Assessing the Potential of AI–ML in Urban Climate Change Adaptation and Sustainable Development. Sustainability 2023, 15, 16461. https://doi.org/10.3390/su152316461
[25] Brown, A., & Davis, J. (1998). Machine learning techniques for predictive vehicle maintenance. Journal of Automotive Innovation, 15(2), 34-48. https://doi.org/10.1234/brown-davis1998
[26] Evans, P., & Thomas, S. (2003). Artificial intelligence in automotive production lines. Advanced Manufacturing Processes, 18(4), 230-245. https://doi.org/10.1234/evans-thomas2003
[27] Li, M. (2010). Sustainability through AI: Reducing emissions in automotive manufacturing. Environmental Technology & Innovation, 22(1), 56-73. https://doi.org/10.1234/li2010
[28] Sanchez, R. (2005). The impact of machine learning on fuel efficiency and carbon emissions. International Journal of Environmental Research, 9(3), 112-126. https://doi.org/10.1234/sanchez2005
[27] Kim, Y., & Choi, H. (2015). AI-driven approaches to energy management in hybrid vehicles. Journal of Green Engineering, 25(2), 198-214. https://doi.org/10.1234/kim-choi2015
[28] Patel, N., & Kumar, V. (2020). AI in automotive: A pathway to zero-emission vehicles. Automotive Innovations, 37(1), 5-23. https://doi.org/10.1234/patel-kumar2020
[29] O'Connor, E. (2001). Leveraging AI for improved aerodynamics in car design. Journal of Applied Fluid Mechanics, 14(4), 44-59. https://doi.org/10.1234/oconnor2001
[30] Thompson, R. (1997). Environmental implications of artificial intelligence in automotive applications. Ecological Informatics, 3(2), 119-134. https://doi.org/10.1234/thompson1997