



A Review of Net Zero for The Automotive Manufacturing Industry

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ABSTRACT

Objective: This article explains the crucial importance of net-zero for the automotive industry.

Method: This article employed a systematic review (the PRISMA method) based on secondary data and content analysis by purposive sampling from scholarly papers published in English, primarily between 2021 and 2025.

Results: Achieving net-zero status for the automotive manufacturing sector signifies attaining a condition in which the aggregate greenhouse gas emissions from a company's complete operations and supply chain are offset by an equivalent volume of carbon sequestration. This extends beyond the emissions produced by a factory, encompassing the entire process from the extraction of raw



materials, such as steel and aluminum, to the energy used by vehicles on the road, as well as their disposal at the end of their lives.

Conclusion: To achieve this, firms are focusing on several key strategies: electrifying their vehicle fleets to reduce tailpipe emissions, utilizing renewable energy sources to power their manufacturing facilities, and collaborating with suppliers to decarbonize the manufacturing of parts. This transition entails a shift towards a circular economy, emphasizing the recycling and reuse of materials, especially the essential components in electric car batteries

Keywords: net zero, car, automotive industry, automobile, sustainable development, sustainability

1. INTRODUCTION

The technologies required to decarbonize the majority of the automotive manufacturing value chain are already available; however, market and regulatory incentives are lacking. To attain carbon neutrality, the industry must implement net-zero manufacturing processes and generate net-zero vehicles. As of this writing, all leading automobile manufacturers have either introduced or are on the verge of introducing electric drivetrain vehicles to the market, while the majority continue to produce and sell vehicles powered by fossil fuels. Countries rich in renewable energy resources may occupy advantageous positions compared to those whose manufacturing or fiscal revenues rely on fossil fuels. This situation presents the opportunity for the relocation and reconfiguration of established industries (Samadi et al., 2021), as well as the potential for nations with renewable energy resources to seize a significantly larger share of the global value chain than currently exists. The demand for carbon offsetting has significantly surged across all sectors of the economy. It is reasonable to assume that individuals in various sectors, including the automotive industry, embrace offsetting. The predominant offsetting measure analyzed is forestation or forest management (Fouqueray et al., 2021). The transportation sector is a crucial component of the sustainability transition (Bassi et al., 2022). The sector plays a significant role in decarbonization and climate change mitigation (Runsén & Junyi, 2021).

The automotive sector's shift towards sustainable development is closely connected to green innovation, which must also facilitate carbon-neutral transportation systems. Research on the sustainability and climate change dimensions of certain components of the automotive innovation



value chain is expanding. The mitigation of CO₂ emissions is crucial, as numerous studies indicate that rising GDP and escalating per capita energy consumption correlate with increased greenhouse gas emissions (Abbas et al., 2021; Sheraz et al., 2022), thereby complicating the achievement of the United Nations Sustainable Development Goals (UN SDGs). The evolution of GHG inventories in the EU suggests that policies aimed at reducing emission intensities and national contributions to sector emissions are failing to achieve their objectives (Poschmann et al., 2022). The regulation of fleet emissions in the automotive sector led to rebound effects, as enhanced efficiencies enabled the operation of larger vehicles in greater numbers, thereby increasing total emissions. The German Federal Ministry for Economic Affairs and Climate Action indicated that multiple sectors exceeded their allocated budgets and must increase their current rate of emission reductions threefold (Federal Ministry for Economic Affairs, 2022). Furthermore, annual deficits will accumulate, necessitating the implementation of supplementary measures to meet future European contributions (Federal Ministry for Economic Affairs, 2022).

Thus, in a net-zero economy, low-emission vehicles would dominate the roadways. For automotive manufacturers, this would entail significant alterations in capital expenditure and workforce levels.

2. LITERATURE REVIEW

2.1 Net Zero and the Automotive Industry

Net Zero for automotive manufacturers refers to achieving a balance between greenhouse gas (GHG) emissions and GHGs removed from the environment, with the ultimate objective of achieving zero net carbon emissions across their entire operations and value chain. A swift shift to solely concentrate on electric vehicle production within a few decades will likely necessitate regulatory measures (IEA, 2021d). Furthermore, decarbonizing vehicle assembly alone will be insufficient. Substantial emissions arise throughout the industry's value chain and life cycle, encompassing the upstream supply chains for materials and the manufacturing of component parts, as well as the end-of-life disposal of vehicles and their various components. Decarbonization must occur at both ends of the upstream supply chain, which involves extracting materials and manufacturing components such as steel, aluminum, plastics, glass, and battery packs, as well as in the end-of-life disposal of vehicle materials and components. The prospects for attaining net-zero emissions, vehicle end-of-life disposal, and material circularity are promising. Technically, it is feasible to recycle nearly 90% of the weight of most vehicles. Establishing the market conditions for comprehensive recycling necessitates both regulatory



interventions and modifications to vehicle designs to facilitate near-total recycling (Weidenkaff et al., 2021).

2.2 Net Zero and Sustainable Development

The energy–food–water–air quality nexus may be significantly impacted by the global net-zero shift required to mitigate climate change. Everyone should strive for net-zero and other environmental goals to achieve sustainable development. Net-zero creates a multi-model interconnectivity evaluation framework to quantify the co-benefits and trade-offs of climate action in support of environmentally sustainable development goals. It is making incomplete progress toward many sustainable development targets. Sustainability improves in energy and water systems during the transition to net zero. However, co-benefits alone cannot sustain energy, food, water, and air quality. Uncoordinated policies may exacerbate energy and food security vulnerabilities as the adoption of fluctuating renewables and bioenergy increases. We recommend pragmatic ways to boost demand management incentives, food system efficiency, modern irrigation technology, and air pollutant control (Zhang et al., 2024).

The net-zero automotive industry must conduct its manufacturing processes without emitting greenhouse gases and produce low-emission products. A transition from internal combustion engine vehicles to electric drivetrain vehicles is the most direct method to attain this objective for the majority of markets and applications. Vehicles are intricate, engineered products characterized by extensive supply chains. Substantial emissions occur in the upstream supply chain prior to automotive assembly. The majority of empirical research and model development concentrates on the macro level.

Setiawan (2021) presents a macro-level analysis of emissions and the effects of policy measures enacted to mitigate CO₂ emissions. The sustainability significance of their method lies in its utility for evaluating the transition to electric vehicle production. They assert that, as China emerges as the preeminent automotive market with increasing production, environmental pressures also escalate concurrently. They are also offering recommendations to mitigate environmental impacts.

2.3 Net Zero, Carbon Footprint, and Sustainability in the Automotive Manufacturers



The sustainability trend of the 21st century has impacted nearly the entire global economy, including the automotive industry. Due to this trend, automobile businesses are adapting their strategy and operations to promote global sustainability. Sustainability is helping the car sector undergo its biggest change. The sustainability strategies of the world's top automotive companies and their fulfillment of UN Agenda 2030 sustainability goals are crucial for alternative provision. The sustainability policies of automotive companies align with most of the UN's sustainable development goals, indicating that they are adapting to modern business needs. This makes their brands green, so sustainability strengthens them and adds “extended customer value”. The paper contributes to the framework and elaboration of sustainability business models in the automotive industry, as well as to theoretical and empirical research and sustainability principles (Lukin et al., 2022).

2.3.1 Decarbonizing Automotive Production

Realizing a transition to net-zero industrial production in alignment with the objectives of the Paris Agreement necessitates substantial policy leadership and investment in energy supply to benefit the entire nation. This requirement exceeds the scope or capacity of any individual business, facility, or industry. Strategic infrastructure at the national level, whether directly or indirectly governed by national authorities, is a crucial element. Additionally, finance and construct a zero-emission power grid, while ensuring access to either imported or domestically produced low-carbon synthetic fuels. Without the necessary supporting infrastructure, businesses may be reluctant or unable to alter entrenched fossil fuel-based production methods or adopt clean alternatives, such as electrifying processes or transitioning to zero-emission fuels. All three countries face a significant challenge in the expedited timeline necessary for transforming energy supply infrastructure, as well as the complexities involved in transitioning from a fiscal and export strategy centered on fossil fuel extraction to one that prioritizes clean energy as the primary resource of the 21st century (Solano-Rodríguez et al., 2021; Welsby et al., 2021).

2.3.2 Pathways to Net Zero Manufacturing Electrification and Beyond

The gradients of decarbonization pathways are contingent upon specific corporate performance. The sectoral decarbonization approach (SDA) employs the proposed convergence strategy, focusing on integrating global emission intensities of critical sectors (Hackelsberger, 2021). The intensity pathways are derived from established mitigation scenarios, ensuring that the cumulative



emissions of all companies do not surpass the absolute carbon budget allocated to each sector annually (Wei et al., 2021). Electric vehicles depend on a decarbonized grid to facilitate a transition to climate neutrality. This involves substituting unmitigated fossil fuel generation with renewable energy sources, nuclear energy, and/or facilitating carbon capture and storage for fossil fuel emissions (IEA, 2021f). Vehicles with reduced weight, utilizing identical batteries and drivetrains, will achieve greater distances; therefore, manufacturers should maintain their emphasis on lighter-weight vehicles.

2.3.3 The Transition to Zero-Emission Vehicles for Sustainable Supply Chains

Vehicle manufacturing relies on the production and assembly of components, which entail various intricate processes that consume substantial quantities of electricity and fossil fuels for high-temperature process heat. The primary methods for attaining net-zero vehicle manufacturing will resemble those employed by other industrial sectors; these methods rely on energy efficiency, the electrification of numerous processes utilizing zero-carbon grid electricity, and the application of green hydrogen for high-temperature process heat (Nilsson et al., 2021). Manufacturers' decisions regarding vehicle product design are critically significant. One of the most effective methods to reduce energy consumption is to decrease the vehicle's mass (Czerwinski, 2021; Shaffer et al., 2021). An additional critical decision pertains to the selection of drivetrain (i.e., liquid fuels or electricity). Decarbonizing internal combustion engine vehicles is challenging due to the difficulties in substituting automotive gasoline and diesel with biogenically derived synthetics or ethanol, primarily because of restricted land use and potential conflicts with food production. This suggests that electric vehicles should be the primary focus for automotive manufacturers in the future. Moreover, the freight transport components of the automotive supply chain, encompassing both finished products and intermediate components, must be electrified or fueled by net-zero liquid or gaseous synthetic fuels. Technological solutions have been identified for decarbonizing road freight (IEA, 2021).

2.3.4 Green Materials and Low-Carbon Logistics in the Auto Sector

More research and policy support are required for both the upstream inputs used in auto manufacturing and the downstream disposal of vehicles. To attain net-zero standards in auto manufacturing, upstream inputs such as steel, aluminum, plastic, and glass require transparent and uniform standards and procedures for emissions accounting. These have not yet achieved widespread establishment. Many automobile manufacturers are eager to incorporate "green steel" into their vehicles (Muslemani et al., 2022); however, a standardized definition of green steel suitable for product standards, labeling regulations, or trade negotiations has yet to be established. The overarching perspective on downstream disposal indicates that it is technically feasible to



recycle nearly an entire vehicle. Nevertheless, the economic and market incentives for comprehensive recycling, as well as for the vehicles to be engineered for near-total recyclability (i.e., approximately 100%), must still be instituted through regulation (Weidenkaff et al., 2021).

2.3.5 Recycling, Reuse, and End-of-Life Strategies Policy, Regulation, and Market Forces Shaping the Net Zero Automotive Future

The technical approaches to recycling over 90% of the steel and aluminum utilized in vehicles are already established and are continually advancing. This pertains to guaranteeing that the requisite infrastructure and market incentives are established at the appropriate scale. Plastics and textiles present distinct challenges for end-of-life disposal. Lead-acid batteries and nickel-metal-hydride batteries, prevalent in hybrid electric vehicles, are extensively recycled with high material recovery rates. Infrastructure and standardized procedures, such as explicit labeling for various chemistries, are essential for managing large-scale electric vehicle battery packs, potentially necessitating regulatory intervention in certain markets. The recycling process, particularly when focused on recovering pure metals instead of entire batteries or components for reuse, is frequently energy-intensive (Fujita et al., 2021) and must shift to utilizing zero-carbon energy sources. Manufacturers can significantly enhance vehicle recyclability during the design phase by choosing materials conducive to recycling and organizing vehicle components for straightforward disassembly for reuse as spare parts or segregation into distinct recycling streams, adhering to standard circular-economy principles (Aguilar Esteva et al., 2021; Baars et al., 2021; He et al., 2021). This is especially relevant to battery packs, as well as other structural elements, such as windshields and wheel rims.

3. METHODOLOGY

3.1 Data Collection

3.3 Data Analysis



4. RESULTS

4.1 Word Clouds

The word clouds show the keywords of this article. The main focus is on automotive, manufacturing, vehicles, production, emissions, sustainability, and related topics.



Figure1. Word Clouds

<https://www.wordclouds.com/> (August 18, 2025)

4.2 Grammarly Results

Grammarly indicates that the grammatical appropriateness is 97%, and plagiarism is approximately 1%.

4.3 Conceptual Model

Reuse, Recycle
Renewable Energy
Low Carbon Emission

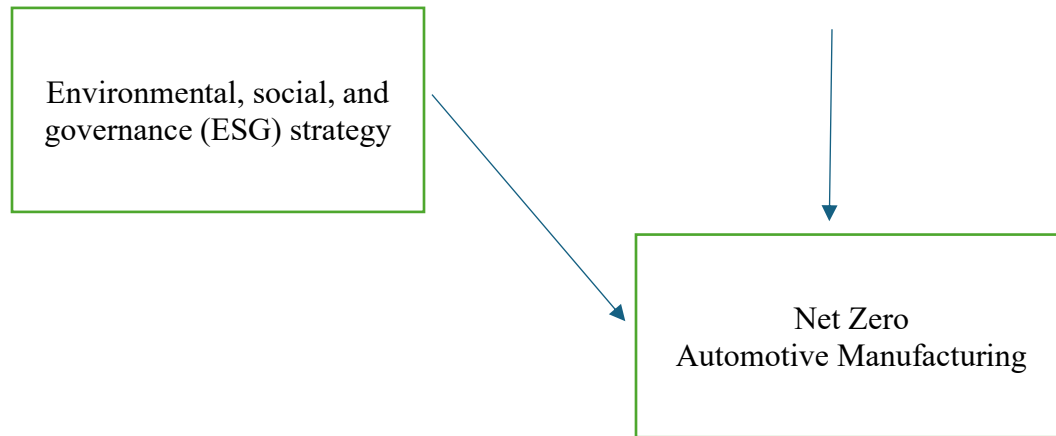


Figure 2. Theoretical Model

5. DISCUSSIONS

Shaffer et al. (2021) concluded that achieving net-zero automotive manufacturing requires synchronized efforts across various sectors, including industrial policy, transportation policy, urban planning, and power grid planning. The technological capacity to decarbonize the majority of the automotive value chain is already present; however, market and regulatory incentives are lacking. Achieving zero emissions from vehicular usage requires collaborative efforts between automobile manufacturers and policymakers across several critical areas and may also necessitate institutional fortification to facilitate the allocation of investments where necessary. Several instances: Neither the zero-emission manufacturing of vehicles nor their zero-emission operation can be realized without a power grid that is itself net zero. The proliferation of electric vehicles is improbable without the strategic development of fast and accessible public charging networks by municipalities, regions, and nations, either independently or in collaboration with industry stakeholders. The industry cannot confidently invest in new designs without assurance of strong markets for its products. Historically, automakers have opposed nearly all health and environmental regulations, including those related to emissions, vehicle efficiency standards, airbags, and seatbelts. There is no justification to expect a change in the regulatory framework



that would facilitate the establishment of a net-zero vehicle fleet. Policymakers must evaluate the entire value chain and life cycle of vehicles, which may necessitate extending beyond merely requiring electric drivetrains. Regulatory measures may necessitate additional actions; for instance, regulations could promote the manufacture of lighter vehicles through weight-based taxation.

This article supports Barrowclough & Birkbeck (2022), Czerwinski (2021), and He et al. (2021) that enhanced material circularity is the primary pathway to attain net-zero emissions during the end-of-life disposal phase in the life cycle of plastics, textiles, and automotive products, including vessels and equipment utilized in fisheries. A substantial body of literature exists regarding circular-economy principles in various sectors, including plastics and automotive manufacturing. Implementation necessitates substantial enhancements in infrastructure for the collection and processing of end-of-life products; the establishment of robust incentives to deter landfill disposal and environmental dumping; and proactive modifications to product design and materials, achieved through regulations or industry collaboration, to prevent the production of non-recyclable items.

Mondal & Shubhra (2024) demonstrate that the automotive sector is undergoing a significant shift towards sustainability, driven by both economic and environmental considerations. Conventional manufacturing methods heavily rely on non-renewable resources, such as steel and polymers, thereby exacerbating environmental degradation and greenhouse gas emissions. In response to escalating governmental restrictions and consumer demand for environmentally sustainable products, automakers are utilizing sustainable materials, such as bio-based polymers, recycled metals, and natural textiles. These materials confer environmental advantages by reducing carbon emissions, conserving resources, and minimizing waste, while simultaneously delivering economic benefits such as improved fuel efficiency, lower production costs, and reduced reliance on volatile resource markets. Incorporating sustainable materials often necessitates modifications to production processes, including retooling and the adoption of new technologies; however, these alterations yield long-term benefits, such as reduced vehicle weight, decreased energy consumption, and improved recyclability. Moreover, advancements such as 3D printing have enabled the utilization of these materials, promoting more efficient production with reduced waste. A lifecycle analysis indicates that sustainable materials can substantially diminish environmental impact during a vehicle's lifespan, from production to disposal. This transition has created new commercial opportunities, as consumers increasingly want automobiles that reflect their environmental ideals. By implementing sustainable practices, the automotive sector can simultaneously address both economic and ecological concerns, thereby positioning itself for future success and demonstrating how sustainability can drive innovation.



6. CONCLUSIONS

Sustainability in the automotive business is gaining significance for manufacturers, suppliers, and investors due to escalating environmental and regulatory challenges. The thought leadership provides professional data and insights into critical automotive sustainability trends, offering a comprehensive perspective on the industry's developing landscape. It provides essential guidance on sustainability for automobile manufacturers and suppliers, helping firms overcome challenges while achieving their environmental objectives. Our analysis examines the potential effects of new rules, emissions standards, and reporting requirements on your operations, assuring your preparedness for the future. Sustainability is a crucial concern for vehicle manufacturers, aiming for a net-zero future by significantly reducing their carbon footprint. This footprint encompasses all greenhouse gas emissions resulting from the company's operations, including energy consumption for factory operations, materials procurement for production, and emissions from vehicles during their use.

Manufacturers are addressing this challenge with a multifaceted strategy. They are expediting the transition to electric and other low-emission automobiles to reduce tailpipe emissions, while concurrently advancing the use of renewable energy sources in their manufacturing facilities. An essential component of their plan is the adoption of a circular economy model. This entails engineering vehicles for durability and employing recycled and sustainable materials, as well as creating mechanisms for the recycling and repurposing of vehicle components, particularly batteries, at the end of their lifecycle. Through the implementation of these methods throughout their operations and supply chains, the automobile industry seeks to reduce its environmental footprint and facilitate the transition to a more sustainable global transportation system. They can capitalize on the opportunities of indirect decarbonization by motivating their customers and suppliers to make climate change commitments and take action. Their behavior may catalyze special climate change-targeted economic cooperation, especially in the case of organizational networks.

To gain a comprehensive grasp of net-zero, carbon footprint, and sustainability within the automotive industry, consider the following two pertinent journal articles:

6.1. "Promoting Sustainability: Eco-Friendly Technology in the Automotive Sector" This article offers a thorough examination of how green technology, including electric vehicles (EVs) and alternative fuels, is propelling the automotive industry's transition to sustainability. It examines the obstacles and advantages of this transformation, emphasizing critical technologies and key



activities. The study examines the concept of a circular economy in the industry, emphasizing the use of renewable materials and the importance of recycling and reusing vehicle components to reduce the overall carbon footprint.

6.2 "Zero Carbon Manufacturing in the Automotive Sector: Incorporating Predictive Analytics to Attain Sustainable Production." This study focuses on the manufacturing dimension of sustainability, arguing that achieving net-zero emissions requires a fundamental transformation in production methodologies. It examines the application of predictive analytics and other sophisticated technologies to oversee and reduce energy consumption and carbon emissions at a detailed level. The article articulates a vision for a "zero-carbon ecosystem" by examining how innovative technologies might dissociate carbon emissions from the manufacturing process, thus establishing a more efficient and sustainable production model.

Manufacturers exhibit a certain level of commitment to investing in net-zero vehicles; however, swift adoption necessitates ongoing policy support and regulation. As of this writing, all leading automobile manufacturers have introduced, or are on the verge of introducing, electric drivetrain vehicles; concurrently, the majority continue to produce and sell vehicles powered by internal combustion engines utilizing fossil fuels. Despite low fuel prices, electric vehicle technology is expected to advance, achieve parity with, and ultimately exceed the performance of fossil fuel-powered vehicles. A separate study focuses on the Automotive Proving Ground in Zalaegerszeg, a distinctive investment that features multiple functions and aims to achieve net zero or reduced greenhouse gas emissions. Companies require additional support to enhance their sustainability performance. A comprehensive and transparent evaluation of GHG mitigation initiatives can help companies establish accountability. The freight-transport components of the automotive supply chain, encompassing both finished products and intermediate components, must be electrified or powered by net-zero liquid or gaseous synthetic fuels for transportation. Ultimately, the disposal of vehicles at the end of their life cycle should be redefined to promote circular material flows. In theory, almost all components of a vehicle are recyclable; however, the vehicle design, recycling infrastructure, and suitable market incentives must be harmonized. Manufacturers can significantly enhance vehicle recyclability during the design phase by selecting materials conducive to recycling and organizing vehicle components for straightforward disassembly, thereby facilitating reuse as spare parts or segregation into distinct recycling streams, in accordance with established principles of the circular. This is especially relevant to battery packs and other structural elements, including windshields and wheel rims.

7. RESEARCH IMPLICATIONS



For automotive manufacturers, Net Zero encompasses not only the production of electric vehicles but also the entire life cycle of automobiles and their associated business operations.

7.1 Manufacturing Emissions and Transitioning to renewable energy sources (solar, wind) for industrial facilities. Utilizing energy-efficient industrial machinery. Minimizing waste and repurposing materials in the manufacturing process.

7.2 Upstream Supply Chain Emissions in Collaborating with suppliers that utilize low-carbon materials (e.g., green steel, recycled aluminum). Localizing supply networks to reduce transportation emissions.

7.3 Promoting sustainable logistics. Emissions from Vehicle Utilization: Transitioning to electric or hydrogen-fueled automobiles. Enhancing energy efficiency in engines and batteries. Facilitating a charging infrastructure with renewable energy sources. Recycling at End-of-Life: Engineering vehicles for circularity (facilitated disassembly, recyclable components). Establishing battery recycling initiatives.

7.4 Carbon Offsetting and Removal: Investing in reforestation, carbon sequestration, or offset initiatives for inevitable emissions.

8. LIMITATIONS AND RECOMMENDATIONS

This article is a systematic review and may not include respondents. Thus, questionnaire or interview surveys are recommended for further studies.

Case studies are recommended, such as

Toyota: Illustrative Measures by Prominent Manufacturers - Hydrogen Fuel Cell Technology and Recycling Initiatives. Tesla: Comprehensive electric product range and renewable energy-powered Gigafactories. Volvo aspires to achieve a fully electric vehicle lineup and climate-neutral production by 2040.

BMW: Sustainable aluminum procurement, circular battery recycling. Significance: Adherence to regulations: Countries such as the EU are enforcing stricter targets for carbon neutrality. Consumer demand: Consumers are progressively favoring environmentally sustainable vehicles. Investor influence: ESG (Environmental, Social, Governance) measures influence corporate valuations.

**Abbreviation:**

GDP :
CO₂ :
UN :
SDGs :
SDA : Sectoral Decarbonization Approach
ESG : Environmental, Social, Governance

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