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Un grazie speciale alla mamma e al papà

.. e anche a tutti gli altri

Mi mancate sempre

Abstract

In the backdrop of a burgeoning global population and escalating urbanization, the pervasive car-consumption culture has reached unsustainable proportions, necessitating a profound revaluation of mobility practices. This master's thesis aims to scrutinize innovation as a strategic avenue to counterbalance the adverse impacts of current mobility trends among the different sustainability dimensions: environmental, social and economic. Grounded in foundational theoretical principles, the research seeks to provide a comprehensive overview and evaluation of contemporary innovation trends within the current landscape. This entails an exploration of both the potential and limitations inherent in these innovations. Additionally, the study extends its gaze towards more long-term-oriented solutions, assessing their viability and envisaging their potential impact on addressing the sustainability challenges embedded in modern mobility and ultimately completely reshaping the concept we have of our mobility system. By offering this nuanced examination, the thesis aspires to contribute valuable insights to the ongoing discourse on sustainable innovation in the realm of mobility.

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List of Abbreviations

EGD	European Green Deal
IEA	International Environmental Agency
EEA	European Environment Agency
ICE	Internal Combustion Engine
EV	Electric Vehicle
OeM	Original Equipment Manufacturer
LoA	Level of Automation
SDGs	Sustainable Development Goals

Introduction

1.1 Problem Statement

In contemporary society, mobility stands as a fundamental thread within the intricate tapestry of consumption activities. The incessantly rising demand for mobility, predominantly fed by the automotive industry, has significantly shaped our cultural habits, urban infrastructure, and economic dynamics over the span of more than a century. However, the current public mobility systems, with few exceptions, have struggled to counterbalance the relentless surge in private vehicle reliance.

This mobility-centric paradigm has given rise to a constellation of pressing issues, primarily of environmental concern. Challenges such as escalating energy consumption, environmental pollution, spatial disintegration, and habitat appropriation have emerged as direct consequences of the automotive industry's pervasive influence. The automobile, deeply ingrained in mass culture, has become a cornerstone of our daily habits and urban infrastructure. Its economic significance has grown to an extent where it is perceived as 'too big to fail,' presenting an entrenched lock-in effect that seems insurmountable.

1.2 Research Objective and Question

Amidst these challenges, a shifting paradigm towards sustainability has begun to take its fledgling steps, propelled by a growing awareness of the environmental impact of traditional mobility practices. The diffusion of sustainable technologies and innovations has initiated changes in consumer behaviours, prompting businesses to follow suit. Recognizing these pressures, institutions are now adopting a systemic approach, marked by initiatives such as the Green Deal that explicitly phases out Internal Combustion Engines and set new target for the urgent development of a sustainable mobility system. However, despite the efforts, the magnitude of the required transformation remains daunting, often offset by countervailing forces**.**

The primary research objective is twofold: firstly, to conduct a comprehensive investigation into the current state-of-the-art innovations within the mobility sector, with a particular emphasis on the paradigm shift towards electric vehicles (EVs); and secondly, to provide an encompassing overview of the contextual and dynamic factors that shape and propel these innovations. This multifaceted approach seeks to go beyond a mere exploration of technological advancements by delving into the broader landscape in which these innovations emerge.

The focus on the "state of the art" encapsulates the cutting-edge developments and transformative shifts occurring in the realm of mobility, specifically highlighting the pivotal transition towards electric propulsion. By scrutinizing the latest technologies, breakthroughs, and industry trends associated with electric mobility, the research aims to offer a detailed portrayal of the current innovative landscape.

Understanding the contextual factors becomes crucial for a holistic interpretation of the innovations, providing insights into the challenges, opportunities, and potential future trajectories within the evolving mobility landscape.

Recognizing the centrality of automobiles in our societal fabric, this thesis embarks on an exploration of future transformative effects and innovation. The core research question driving this inquiry seeks to identify which of these might culminate in reshaping our conceptualization of mobility and guide us toward a sustainable future. As we navigate the nexus of innovation, societal habits, and environmental imperatives, the thesis endeavours to contribute insights that propel us beyond the current impasse and towards a future where mobility seamlessly integrates with sustainability.

1.3 Structure

The first section –chapter 2- involves the construction of a robust theoretical foundation, serving as the touchstone for assessing the subsequent discourse on innovation. This discourse is particularly focused on the three-dimensional model of sustainability, investigating the intricate trade-offs inherent in the implementation of solutions towards sustainability applied to the mobility sector.

The analysis is also oriented into the investigation of the actors involved in the innovation process, namely users, institution and innovators. The interplay between institutional initiatives and practical application will also be central. The Green Deal Plan for Mobility serves as an illuminating case study in this regard, characterized by ambitious objectives and profound consequences that have reverberated throughout the industry, reshaping its contours.

Chapter 3 adopts a first contemporary short-term approach to envision the effects of these structural transformations. Within this context, the ascendancy of Electric Vehicles (EVs) emerges as a focal point, exerting a momentous impact on the gradual phasing out of Internal Combustion Engines (ICEs). This section is dedicated to the thorough evaluation of the benefits accrued from this paradigm shift, highlighting the potentials and trends it generated. Notably, the disruptive features instigated by the proliferation of EVs are explored, paving the way for synergies and innovations that chart a transformative trajectory for the industry.

Transitioning towards a longitudinal perspective, the chapter 4 envisages potential innovations that extend beyond the immediate horizon. Automated driving systems and the conceptualization of Mobility as a Service (MaaS) stand as prominent exemplars within this futuristic exploration. These innovations intricately interweave with other cutting-edge advancements, including Big Data analysis and the Internet of Things (IoT) and synergistically leveraging the inherent potential of Electric Vehicles which stands out as a fundamental step in the innovation towards sustainability as it will be further discussed in the final section regarding Conclusions in section 5. Chapter 6 will then summarize results and highlight further questions for future research.

2. Theoretical Framework: Sustainable Mobility

2.1 Pivotal Role of Mobility

The freedom to move not only empowers individuals to explore new opportunities but also enables them to pursue education or employment in diverse locations, providing access to crucial healthcare services and more. Physical mobility becomes a catalyst for personal development and a manifestation of autonomy, allowing individuals to actively shape their lives and surroundings. In this context, mobility transcends beyond a mere physical act; it evolves into a means for individuals to achieve self-determination, emerging as a fundamental right (Berg & Newmark, 2020).

The emergence of sustainability challenges in the realm of mobility is intricately linked to the extensive socio-geographical transformations witnessed in the past century. Urbanization, suburbanization, centralization, mass travel, migration, and globalization have collectively fueled the discourse on the sustainability of mobility. Recognizing the pivotal role mobility plays in our lives, this debate has become increasingly prominent. According to the European Environmental Agency (EEA), as highlighted in its report 'The European environment —state and outlook 2020,' categories such as food, mobility, and housing, along with the energy sector, stand out as key drivers of environmental pressures. Their impact is seen as a natural consequence of the indispensable roles they fulfill.

Integrating the concept of sustainability into this discourse, as articulated by Korshunova et al. (2020), "sustainable mobility" is characterized by human freedom in spatial movement that does not compromise the environment or the well-being of others. Sustainable mobility necessitates a transport model that encompasses all dimensions of sustainability. Essentially, a sustainable transport and mobility system is one that facilitates the movement of people and goods in environmentally, economically, and socially sustainable ways (Rossi et al., 2009).

2.2 Three-Dimentional Sustainable Mobility System

2.2.1 Environmental Dimension

The environmental dimension of the sustainability issue is undeniably the focal point of concern. Drawing from the insights of the 'The European environment — state and outlook 2020' (EEA, 2020) report, we can pinpoint four primary detrimental consequences of mobility's impact on the environment.

1. Greenhouse Gas Emissions & Air Pollution: The transport sector stands as a significant contributor to greenhouse gas (GHG) emissions, globally accounting for 31% of the total GHG emissions. Notably, road transport constitutes a substantial portion, contributing one-fourth to the overall emissions when excluding maritime and aerial means (EEA, 2020). A critical observation is the positive trend in the emissions share of the mobility sector, indicating a 26% increase from 1990 to the present. This rise is attributed to the surge in car ownership and heightened transportation demand, offsetting the positive impact of technological progress and institutional efforts, such as the implementation of European emission standards. Studies have identified elevated concentrations of air pollutants, including CO, NOx, NO2, PM10-2.5, PM2.5, PM0.1, BC, and benzene, near major roads due to motor vehicle operations, emphasizing the localized impact of emissions (Baldauf et al., 2008).
2. Resource Intensity & Energy Consumption: The mobility system's resource-intensive nature heavily relies on fossil fuels, particularly oil. In 2016, mobility and transport accounted for 33% of the EU's final energy consumption, with a mere 7% sourced from renewables (Eurostat, 2018). The persistent reliance on fossil fuels creates a 'lock-in effect,' making the transition to alternative and sustainable energy sources challenging. This effect is perpetuated by existing infrastructure, technological dependencies, and deeply ingrained practices within the current fossil fuel-centric mobility paradigm.
3. Habitat Fragmentation & Urban Sprawl: Infrastructure supporting road transportation significantly contributes to habitat fragmentation and urban sprawl, visible effects with far-reaching consequences. Scientific literature affirms the role of road transportation in inducing habitat fragmentation, impacting biodiversity, wildlife populations, and ecosystem functionality. While habitat fragmentation can yield both positive and negative outcomes for biodiversity, the magnitude of these effects is overshadowed by the consequences of habitat loss (Hornseth et al., 2014). Habitat loss is particularly relevant, considering the crucial role of green areas in mitigating the effects of GHG emissions and air pollution.
4. Noise Pollution: Prolonged exposure to road traffic noise poses various health risks, including stress, sleep disturbances, cardiovascular problems, hearing loss, and impaired cognitive function. Furthermore, noise pollution adversely affects wildlife, interfering with communication, foraging behaviours, and breeding activities.

Addressing the environmental challenges stemming from road transportation requires a nuanced approach due to the intricate interplay of various factors. The essential need for mobility and the subsequent demand for transportation create a cause-and-effect loop extending beyond technological solutions like zero-impact powertrains. This complex relationship underscores the necessity for a systemic approach, acknowledging that challenges like habitat fragmentation and urban sprawl are deeply entrenched in societal, economic, and infrastructural systems. Therefore, comprehensive strategies are imperative, extending beyond technological advancements alone (Holden et al., 2019).

2.2.2 Socio-economical Dimension

The socio-economical dimension of sustainability is often overlooked in many circular and sustainability projects, with an overemphasis on one dimension and disregard for another (Dytianquin et al., 2023). In the realm of transportation, sustainable mobility strives to provide safe, effective, and efficient access while concurrently addressing the economic, social, and environmental needs of society (Rossi et al., 2009). This underscores the imperative of harmonizing the sustainability triad, embracing environmental, social, and economic dimensions for comprehensive sustainability.

As highlighted by the EEA in 'The European Environment — State and Outlook 2020' (2020), the economic dimension of the transport sector is generally defined as an economic activity. This definition encompasses key indicators like Gross Value Added (GVA), employment rates, the number of enterprises, and more. Within this economic dimension, the emphasis rests on cost-effectiveness, ensuring the long-term economic viability of transportation solutions and related business activities. This involves consideration of initial investments, operational costs, and overall economic benefits. The economic dimension also plays a pivotal role in job creation across sectors such as public transportation, electric vehicle manufacturing, infrastructure development, and sustainable urban planning. Furthermore, it supports economic development by facilitating the movement of goods and people, fostering trade and commerce, and attracting investments to both urban and rural areas.

Contrastingly, the mobility system encompasses elements beyond mere economic activity, delving into realms such as personal mobility, individual behaviours, infrastructures, urban and regional planning, investments, policy and regulatory measures, and the involvement of diverse actors including producers, users, policymakers, and civil society.

Within the social dimension, the focus centres on equity and accessibility. Disparities in access to transportation resources can pose challenges to daily mobility, amplifying socio-economic inequalities and impeding access to essential services like education and healthcare (Lejoux et al., 2019). This dimension also entails addressing public health issues associated with the drawbacks of the environmental dimension, including concerns such as air and noise pollution, road accidents, and physical inactivity. Efforts should be directed towards enhancing community well-being by mitigating negative externalities while promoting social inclusion through affordable and accessible transportation options that connect people to essential services, employment, education, and social activities.

2.3 Sustainable Mobility Trade-offs

The triad of ecological, economic, and social pillars within sustainable mobility is a well-acknowledged concept in the literature (Biehle, 2022). Mobility practices are both influenced by and influence this intricate network of individual, social, and environmental factors. Recognizing the need to understand the synergy between individuals and their mobility environment for behavior change toward sustainable mobility is crucial (Bergman et al., 2019). The sustainable mobility paradigm, exemplified by objectives such as reducing car use, enhancing public transport, and addressing urban sprawl, underscores the interconnectedness of economic, social, and environmental aspects (Banister, 2008; Almatar, 2022). As an illustration, this interplay among the three dimensions may result in potential negative trade-offs affecting the economic aspect, particularly represented by the private car market.

Assessing the contemporary significance of the automotive industry based on Eurostat data (2023), it becomes imperative to evaluate the potential consequences these specified objectives could entail, threatening a sector that holds a substantial role, contributing to 7% of total EU employment and providing both direct and indirect employment opportunities for over 13 million Europeans.

The literature on sustainable mobility emphasizes the complexities and trade-offs between and within the three sustainability dimensions, underscoring the need to understand and address these trade-offs for sustainable urban development (Lerpold et al., 2021). In this three-dimensional model of sustainability, the absence or skewing of one element renders the others unsustainable. A stable economic dimension is crucial for supporting environmental sustainability—an extensively debated concept as exemplified in Stern's work 'The Economics of Climate Change: The Stern Review' (2007) and the Kuznets curve principle as examined by Hassan et al. (2020). The Kuznets curve suggests that a society redirects its attention to environmental issues only after achieving a certain level of economic well-being. This occurs due to both what could simplistically be termed as prioritization reasons as well as due to lacking technological development, which is attained only beyond a certain threshold of economic well-being and stability.

Simultaneously, sustainable development efforts may inadvertently contribute to social inequalities, negatively affecting the social dimension. Initiatives prioritizing economic growth and environmental conservation have faced criticism for potentially exacerbating systemic injustices (Kotzé & Adelman, 2022). The complexity of economic systems and the mediating effects of income inequality impact sustainable development realization in developing countries (Caous & Huarng, 2020).

A tangible example in the mobility and automotive sector is the transition from internal combustion engines to electric motors, driven by sustainability goals and regulations, increasing costs for automakers (Chen et al., 2022). The heightened production costs affecting end prices can constrain the purchasing power of lower-income groups, representing a potential adverse consequence of sustainability efforts within the social dimension.

Trade-offs abound in sustainable mobility development, as illustrated by the work of Lerpold et al. (2021) focusing on urban planning. Examples include environmental impact vs. mobility needs, equity and accessibility vs. efficiency, mode shifts vs. infrastructural investment, cost vs. accessibility, technological innovation vs. infrastructural development, and behavioral change vs. comfort and convenience.

Understanding and navigating these trade-offs in sustainable mobility development are crucial for decision-making that impacts various aspects of sustainable development. This involves considerations of welfare, infrastructure, and natural environment management (Nerini et al., 2017). Policymakers play a pivotal role in coordinating the private sector through incentives and the promotion of sustainability initiatives, considering the complex and intertwined nature of the mobility and transportation sectors.

Predicting trade-offs within a sustainable development plan is particularly intricate due to external factors influenced by the significant weight and central role of mobility and transportation in our lives and production-consumption activities. As defined by the EEA report (2019), energy, mobility, and food systems are central to production-consumption systems due to their essential role in meeting human needs, their interconnectedness, environmental impact, economic significance, resource intensity, and social implications. These external factors are not directly under the control or responsibility of the mobility system alone; rather, they both influence and are influenced by it.

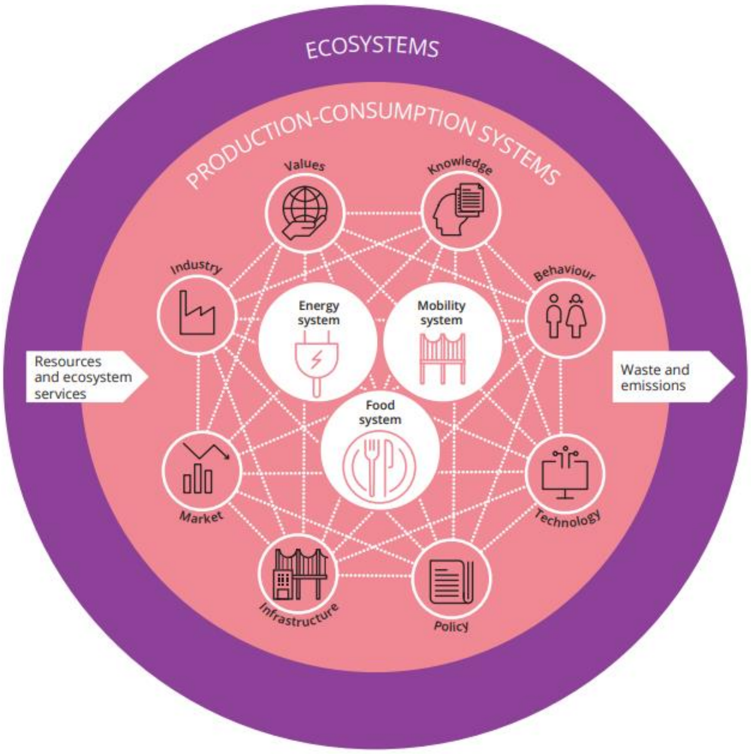


Figure 1- Production - consumption system network
(The European Environment — State and Outlook 2020)

The interconnected nature of these factors, as illustrated in the figure extracted from the EEA report (The European Environment — State and Outlook 2020, 2020), gives rise to an infinite array of variables that are inherently unpredictable, exhibiting temporal instability and geographical variability.

Given its complexity, addressing the sustainable mobility problem necessitates adopting a holistic and systemic approach, as widely recognized in academic literature as essential for achieving sustainable urban mobility (Gillis et al., 2015). This systemic approach is crucial for decision-making in Sustainable Urban Mobility Plans (SUMPs), aiding in the reduction of negative externalities related to urban growth and transportation activities (Chatziioannou et al., 2020). The growing recognition of the need for a more holistic systems approach arises from the imperative to effectively address sustainability by considering complex, systemic interconnections, and cause-and-effect relationships—namely trade-offs.

Turning trade-offs into synergies is considered possible and involves identifying areas of conflict or competition between different goals or objectives and finding ways to align them for mutually beneficial outcomes. This concept draws from the analysis of multiple studies, especially those conducted by Nerini (Nerini et al., 2018) and Kroll (Kroll et al., 2019), where 6 key points underlying an effective strategy in transforming trade-offs arising from the three-dimensional model into synergies were identified as follows:

1. **Integrated Planning:** Integrate cross-sectorial planning to identify emerging trade-offs early on. Considering multiple perspectives simultaneously facilitates finding common ground and synergistic opportunities.
2. **Systems Thinking:** Embrace a holistic view for comprehensive understanding of complex interconnections and cause-and-effect relationships.
3. **Multi-Stakeholder Engagement:** Collaborate with diverse stakeholders to develop inclusive strategies that address trade-offs and create synergies.
4. **Innovation and Technology:** Explore innovative approaches to reconcile conflicting goals, such as using renewable energy sources for simultaneous environmental and economic benefits.
5. **Policy Coherence:** Ensure alignment in policies across sectors to avoid conflicting priorities. Coordinating efforts maximizes synergies and minimizes negative impacts.
6. **Monitoring and Evaluation:** Establish robust mechanisms to track progress and assess impacts regularly. Adjustments can be made to optimize synergies and address emerging trade-offs.

2.4 Role of Innovation

As emphasized in the summary of Nerini and Kroll's works (point 4), innovation stands out as a cornerstone of sustainable strategies. Recognized as a critical driver of economic growth and a means to escape the Malthusian trap, innovation is spurred by competition and imitation, positively impacting economic growth and societal welfare (Aghion et al., 2001). Empirical evidence supports the positive relationship between entrepreneurship, technological innovation, and economic growth (Feki & Mnif, 2016).

Economically, the shift towards sustainable mobility is acknowledged as a catalyst for innovation, job creation, and economic resilience. Investments in green transportation infrastructure stimulate economic growth and foster a competitive industry (The European Environment — State and Outlook 2020). Integrating sustainability into business models creates balanced social, environmental, and economic value (Bocken et al., 2013). The objective is to optimize resource use, minimize waste, and reduce environmental impacts, fostering more efficient and resilient transportation systems for economic sustainability.

Innovation, particularly in cutting-edge technological solutions, plays a key role in addressing sustainability problems. The prevailing perspective on private vehicles in the current transportation paradigm, especially the automotive industry's focus, is noted. Despite this emphasis, private automobile use is deemed unsustainable from environmental and social perspectives, particularly in developing countries (Daniere, 1999).

The historical automotive sector relied on incremental innovation with long product development cycles. However, this incremental nature posed limitations toward sustainability objectives, as efficiency improvements were often offset by demand growth or market trends (EEA, 2019). Disruptive innovation is recognized as vital in driving systemic changes, challenging the status quo, and steering towards a more balanced and sustainable model, aiming to reduce the existing 'car per capita model' (Mäkinen, 2019).

The objective is not to prohibit car use but to design cities and infrastructure systems of such quality and scale that people do not need to own cars (Banister, 2008). Innovation solutions for sustainable mobility should focus on closing the gap between private and public transport means.

The automotive industry has undergone a significant shift with the emergence of electric vehicles, autonomous driving, connectivity services, and shared mobility options. Start-ups and tech companies challenging traditional automakers have introduced innovative business models and technologies. This shift has accelerated due to digital technologies, changing consumer preferences, and sustainability concerns (Ferras-Hermamdez, 2017).

Technological innovations in the automotive sector result from cumulative efforts and, in the long term, can lead to disruption. The convergence of automotive and tech, integrating hardware (e.g., advanced sensors, drivetrain technology) and software (e.g., autonomous drive, infotainment), can pave the way for new business models like Divers Mobility, bridging the gap between an inefficient public transport system and regular car ownership.

In addressing sustainability trade-offs and developing sustainable practices, a holistic and systemic approach is crucial. The complexity of the mobility system calls for an exploration of innovative solutions within the broader spectrum of hybrid mobility, bridging the gap between private and public modes as a viable alternative.

2.5 Role of Users

Active user participation stands at the core of advancing sustainable mobility, playing a pivotal role in cultivating environmentally conscious behaviours. The implementation of personalized strategies, as underscored by Anagnostopoulou et al. (2018), emerges as a crucial element in guiding users toward sustainable transportation choices. Acknowledging users' perceptions of the positive environmental impact of public transport becomes imperative, influencing their transportation mode and effectively reducing reliance on less sustainable options (Gómez-Ortega et al., 2023).

Delving into the realm of behavioural shifts, research highlights the potential for users of single-occupancy vehicles (SOVs) to transition toward more sustainable mobility options, with demographic and location nuances playing a significant role in facilitating this shift (Pan & Ryan, 2022).

Public involvement takes centre stage in fostering attitude and behaviours changes toward more sustainable modes of transport, as emphasized by Gil et al. (2011). Additionally, the integration of technological tools proves instrumental in motivating physical activity, pointing towards the significant role that technology can play in promoting sustainable mobility behaviours (Munson & Consolvo, 2012).

The innovative concept of Mobility as a Service (MaaS) – as it will be explored later - adds a novel layer to sustainable transport, aligning with the idea of leveraging travel behaviours and personality profiles to encourage sustainable transportation choices, as proposed by Anagnostopoulou et al. (2018). However, transitioning to sustainable mobility practices requires a comprehensive approach. Whittle's study (2019) highlights the imperative for policymakers and researchers to delve deep into user attitudes, behaviours, and preferences. This comprehensive understanding becomes paramount in effectively promoting the adoption of sustainable transportation options (Whittle et al., 2019).

Shifting the focus to the social dimension, innovation unfolds its disruptive potential, addressing societal needs and contributing to overall well-being (Jirón & Carrasco, 2019). The significance of user-centric approaches and policy alignment with user needs is underscored by Whittle et al. (2019). Such alignment proves to be essential in facilitating the transition to a more sustainable and environmentally friendly mobility system.

Aligning policy delivery with users' preferences and behaviours emerges as a critical step in encouraging the uptake of low-carbon mobility options. This might involve offering incentives, reducing barriers, and providing information and support to facilitate behavioural change. The potential integration of vehicular emissions policy into transport policy further emphasizes the importance of public acceptability (Angnunavuri et al., 2019).
As we contemplate the future, the journey toward sustainable development will require new geographies and the reorganizations of social and socio-ecological relationships in time and space (Franberg et al., 2010).

2.6 Role of Institutions

Innovation and user engagement play pivotal roles in addressing sustainability challenges. The significance of innovation lies in its ability to uncover and implement solutions to environmental, social, and economic issues. As users actively interact with and adopt these innovations, their feedback becomes indispensable, ensuring that sustainable solutions are not only effective but also user-friendly, tailored to their needs. Simultaneously, institutions are instrumental in spearheading sustainability initiatives by uniting and coordinating efforts toward common development goals (Dasgupta & Cian, 2018).
The escalation of global challenges, such as climate change, resource depletion, and social inequality, has prompted societies worldwide to elevate sustainability as a top priority. Organizations and institutions wield substantial influence over policies and regulations that endorse sustainable practices. By aligning their actions with overarching development goals, these entities contribute significantly to systemic change. Furthermore, they can foster innovation and facilitate the adoption of sustainable technologies through avenues such as research funding, incentivizing innovation, and creating collaborative platforms for diverse stakeholders (Biermann et al., 2012).

2.7 European Green deal for Mobility

Environmental Awareness

In these regards the United Nations in 2014 deployed Sustainable development goals plan (SDGs) to address sustainability challenges on a global scale (Biermann et al., 2012), a collection of 17 objectives with 169 targets established in 2015 to guide efforts towards sustainable development until 2030. They address critical issues such as poverty alleviation, environmental conservation, and social equity, with the overarching goal of fostering a more sustainable and fair world for all (Blanc, 2015). The SDGs serve as a framework for institutions to align their strategies and policies with global sustainability objectives (Caiado et al., 2018).

Following the SDGs plan, the European Union developed the European Green Deal plan (EGD), which can be seen as a regional implementation strategy aligned with the broader global sustainability agenda (United Nations SDGs).

The European Green Deal (EGD) is a comprehensive and ambitious policy framework introduced by the European Commission in December 2019. It aims to guide the European Union (EU) towards achieving climate neutrality by 2050 (Sikora, 2020) through a comprehensive strategy with strong emphasis on resource efficiency, greenhouse gas emissions reduction, and economic growth decoupled from resource use (Gheuens, 2023). Furthermore, the EGD aims to change how the financial system allocates capital and manages green investments for innovative projects and businesses (Long & Blok, 2021).

The SDGs have been heavily criticized for having a too broad set of objectives; concerns about the practicality of implementation, especially in developing countries with limited resources and capacity; lack of a robust monitoring and evaluation framework for tracking progress; excessive focus on economic growth and therefore missing the negative trade-offs among the social and environmental dimensions of sustainability (Singh, 2016). Critics argue that the SDGs fail to sufficiently tackle the underlying causes of global issues like poverty, inequality, and climate change. The plan is perceived as overly ambitious given its worldwide scope and the resulting diversity in social and geographic contexts.

On the other hand, the EGD has the potential to address many of these limitations. The regional character first of all offers a more homogeneous socio-economical context. Through this homogeneity, a more holistic and systemic approach to production and consumption along value chains can be achieved (Sanyé-Mengual & Sala, 2022). Moreover, the Green Deal presents a much more focused set of objectives, emphasizing sustainability and green solutions, which are crucial for achieving healthy and sustainable urban life, highlighting the importance of technology in overcoming limitations (Tarek, 2023).

Targeted approach

Being the only sector among major consumption activities to exhibit a negative trend in terms of emission levels since 1990 (+33%), the mobility sector has therefore represented a key obstacle to decarbonisation in Europe (ICCT), this has inevitably led it to have a central role within the Green Deal plan (Butnaru-Troncotă & Snspa, 2020).

In March 2023 the EU Parliament in Strasburg definitely approved the new binding set of target for the Green Deal Mobility strategy plan proposed in 2021 (Mobility Strategy, 2021):

By 2030: emissions must be reduced by 55% for cars compared to 2021 levels

- at least 30 million zero-emission cars will be in operation on European roads
- 100 European cities will be climate neutral.
- high-speed rail traffic will double across Europe
- scheduled collective travel for journeys under 500 km should be carbon neutral
- automated mobility will be deployed at large scale

By 2050

- nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission.
- rail freight traffic will double.
- a fully operational, multimodal Trans-European Transport Network (TEN-T) for sustainable and smart transport with high speed connectivity.

(Mobility Strategy, 2021)

To make these goals a reality, the strategy identifies a total of 82 initiatives in 10 key areas for action ("flagships") revolving around 3 pillars namely Sustainability, Smart and Resilience.

- ❖ Sustainable: The goal involves boosting zero-emission vehicles, renewable fuels, and infrastructure, creating eco-friendly airports and ports, promoting healthy mobility with increased high-speed rail and cycling infrastructure, greening freight transport, and implementing fair carbon pricing and user incentives.
- ❖ Smart: Innovation and digitalization drive the future of transportation, hinging on favourable conditions. The strategy aims to enable connected and automated multimodal mobility, streamlining ticket purchases for passengers and facilitating seamless freight transitions. It emphasizes innovation, data utilization, and artificial intelligence for smarter mobility, including supporting drone deployment and establishing a European Common Mobility Data Space.
- ❖ Resilient: In response to the COVID-19 impact on the transport sector, the Commission pledges to strengthen the Single Market by completing the Trans-European Transport Network (TEN-T) by 2030 and investing in fleet modernization. Additionally, the commitment extends to ensuring fair and accessible mobility for all, while prioritizing

safety and security across transport modes, aiming to reduce the death toll to near zero by 2050.

Systemic Approach and support

To meet the ambitious targets outlined in the European Green Deal, the Commission is dedicated to mobilizing a minimum of 1 trillion euros in sustainable investments over the next decade. A substantial portion of the EU's Long Term Budget (2021-2028) and the NextGenerationEU (NGEU) recovery instrument, have been earmarked for green investments. EU member states are mandated to allocate at least 37% of funds received through the 672.5-billion-euro Recovery and Resilience Facility to investments and reforms supporting climate objectives. However, these investments must not compromise the EU's environmental goals significantly. The Commission aims to generate 30% of NGEU funds through the issuance of green bonds ((*Recovery Plan for Europe*, 2020).

To support the transition to sustainable mobility and achieve these objectives, the European Union has implemented various initiatives. Notable among these are:

- ❖ Fit for 55: This initiative involves revising and updating EU legislation and introducing new measures to ensure a socially fair transition that enhances innovation and competitiveness in the EU industry. Key components include reinforcing the EU emission trading system (EU ETS), establishing a Social Climate Fund (fed by external assigned revenues up to €65 billion), implementing the Carbon Border Adjustment Mechanism (CBAM), and other initiatives aligning with agreed-upon climate goals.
- ❖ Clean Vehicles Directive: This directive sets targets and monitors the public procurement of clean and energy-efficient vehicles, promoting the adoption of electric and low-emission vehicles in public fleets.
- ❖ European Battery Alliance (EBA): The EBA is a strategic plan to create a competitive and sustainable battery cell manufacturing value chain in Europe. With support from the European Investment Bank, the Alliance brings together 440 stakeholders, including industrial and innovation actors, to strengthen the European competitiveness in the electric car industry.
- ❖ EIT Urban Mobility: An initiative by the European Institute of Innovation and Technology, EIT Urban Mobility aims to be the largest European initiative transforming urban mobility, focusing on a systemic approach, stakeholder engagement, and citizen awareness.

The Green Deal's vast scope and complexity make presenting a well-defined framework challenging. Nevertheless, through reflections and comparisons with existing theoretical frameworks, the relevance to literature on sustainability, climate change, and policy implementation is evident.

In February 2023, the European Union introduced the Green Deal Industrial Plan, comprising four pillars: faster permitting, financial support, enhanced skills, and open trade (Global EV Outlook 2023 – Analysis - IEA, 2023). The plan also includes provisions for the Critical Raw Materials Act, emphasizing security of supply, extraction and environmental standards, and recycling. The Net Zero Industry Act, proposed in March 2023, seeks to meet 40% of the EU's strategic net zero technology needs with EU manufacturing capacity by 2030. This includes battery and storage technologies, aiming for nearly 90% of the EU's annual battery demand to be met by EU manufacturers, aligning with the European Battery Alliance objectives. The plan addresses challenges by streamlining planning approvals, providing financial support, reskilling workers, and enhancing trade resilience (Global EV Outlook 2023 – Analysis - IEA, 2023).

First and foremost, the Green Deal embodies a systemic and targeted approach to sustainability issues. It recognizes the interconnectivity and interdependence of economic, social, and environmental factors, as emphasized in the Sustainable Development Goals (Makaroff & Kalcher, 2023). It takes into account the interactions between different goals and objectives, understanding that pursuing one target can have cascading effects on others (Hughes & Johnston, 2005), as testified by the social climate fund or the addressed need of reskilling the workforce to meet the demands of a green economy.

Furthermore, the Green Deal aligns with the literature's emphasis on careful planning, in its aim to forecast strategic objectives and weaknesses to support the industry transition (Krämer, 2020). Moreover, the Green Deal emphasizes the importance of stakeholder engagement, throughout the implementation process (Makaroff & Kalcher, 2023) by actively involving various stakeholders such as industries, communities, and civil society in the decision-making process, the Green Deal ensures that diverse perspectives and expertise are taken into consideration, allowing for more informed and inclusive decision-making (Krämer, 2020).

2.8 Automakers Answer

The Green Deal and the imminent end of internal combustion engine (ICE) vehicles have catalysed significant responses from global Original Equipment Manufacturers (OEMs). As governments advocate for the phasing-out of traditional vehicles and enforce stringent emissions regulations, OEMs are at a pivotal juncture. Navigating safety standards, emissions regulations, and the imperative for innovation and sustainability pose considerable challenges in the dynamic mobility sector (Lerpold et al., 2021).

According to Mazur et al. (2013), OEMs express apprehensions about the risks and opportunities linked to transitioning to electric mobility. Despite the substantial costs associated with electric vehicle (EV) production and initial consumer reluctance, OEMs are compelled by shifting consumer preferences towards sustainable transportation options (Bohnsack et al., 2020). This positive shift in consumer behaviours, coupled with technological advancements, propels the industry forward.

The automotive industry's response to sustainability imperatives is evident in the strategic commitments of major OEMs. Notably, key players have set ambitious targets, often surpassing institutional deadlines, as detailed below (source (Duffy, 2023)):

- Volkswagen Group: expects half of its vehicle sales to be electric by 2030 and to be nearly 100 percent EV by 2040.
- Volvo: announced plans to be EV only by 2030
- General Motors: Aiming for an all-electric line-up by 2035, targeting zero tailpipe emissions.
- Nissan: Pledged to electrify all new models in key markets by the early 2030s.
- BMW Group: Targeting at least 50% of global sales to be electric vehicles by 2030.
- Audi: pledged to go electric by 2033. The brand will launch its last new internal combustion car in 2026.
- Mercedes-Benz (Daimler): Ambition to have a fully electric line-up by 2030.

'To navigate change, OEMs must reassess models, prioritizing collaborations' (Shifting Gears in Auto Manufacturing, 2020).

As the automotive industry navigates the complexities of electrification, emissions regulations, and policy frameworks post the Green Deal, synergistic efforts between OEMs, tech, and energy firms, emerge as pivotal (Saperas & Legarreta, 2012). On the other hand, government collaboration is crucial to navigate emissions regulations and policy frameworks (Mazur et al., 2013). OEMs align efforts with standards, ensuring compliance and contributing to industry-wide sustainability measures.

In the aftermath of the Green Deal, the automotive industry has witnessed a transformative shift, fostering innovation and collaborative efforts across various domains. From the exploration of sustainable fuel alternatives to the development of advanced battery technologies and strategic partnerships, the post-Green Deal era has propelled OEMs into a dynamic landscape of sustainable innovation. This shift not only addresses environmental concerns but also underscores the industry's commitment to adaptability, collaboration, and cutting-edge advancements for a greener future (Jonnalagedda & Saranga, 2019; Kohar et al., 2020).

3. Short-Term Trends in the Automotive and Mobility Sector

3.1 EV Technology

Battery Electric vehicles (BEV) are recognised by literature to be the single most important technology for decarbonizing the transport sector (Knobloch et al. 2020). Brown et al. (2018) highlight the synergies between the electricity sector and transport, emphasizing the importance of electric vehicles in achieving a cost-optimized, highly renewable European energy system. BEV are several times more efficient at converting energy into vehicle propulsion than gasoline and diesel vehicles, with much lower life-cycle emissions. By 2050, electric power will have to dominate the light vehicle segments and make significant inroads in the heavy-duty categories (ICCT, 2024).

3.1.1 Diffusion

While alternatives like hydrogen technology have been considered for sustainable road transport, the focus has now predominantly shifted towards battery electric vehicles due to their current viability and readiness for deployment in both passenger and freight transport (Plötz, 2022).

Despite the first electric car dating back to 1888, the German Flocken Elektrowagen, and other models making appearances throughout the last century, such as the Peugeot VLV (1941) or the Nissan Tama (1947), the introduction of the lithium-ion battery by Sony in 1991 and A&T Battery in 1992 marked the initial steps towards powering portable electronic tools (Ferrara et al. 2021). The development of advanced lithium-ion batteries has been crucial in driving the EV revolution (Etacheri et al., 2011). However, it was not until the early 2010s that electric vehicles started gaining traction in the automotive market.

The growth of the electric vehicle global market has been dynamic (as shown by figure 2, provided by IEA, GEVO-2023), with the share of electric cars steadily increasing despite slight economic slowdowns due to events like the COVID-19 pandemic (Brdulak et al., 2021). By 2021, the penetration rate of New Energy Vehicles (NEVs) in China had reached 15%, indicating a significant increase in adoption (Liu et al., 2021).

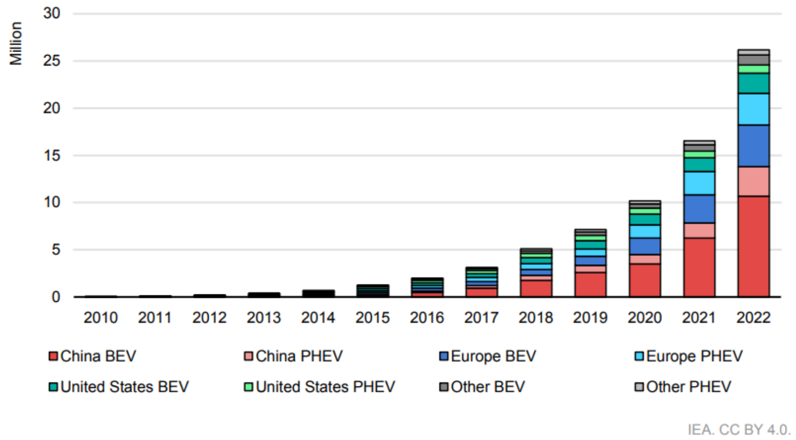


Figure 2 – Global electric car stock per region (IEA, GEVO 2023)

'Over 26 million electric cars were on the road in 2022, up 60% relative to 2021 and more than 5 times the stock in 2018 (IEA- Global EV Outlook 2023)'

The automotive industry is currently in a phase characterized by the coexistence of various technologies and design approaches, reflecting a hybrid state where consumer preferences and needs are not entirely met by a single best design product. Hybridity encompasses not only the technological aspects but also extends to consumer demand, as highlighted by literature (Krishnan & Ulrich, 2001). This is evident in the development and adoption of electric and hybrid vehicles, as highlighted by Farooq et al. (2016) and (Kellner et al., 2022) as well as by the data provided by International Agency Agency (IEA) report Global EV Outlook 2023 (GEVO 2023).

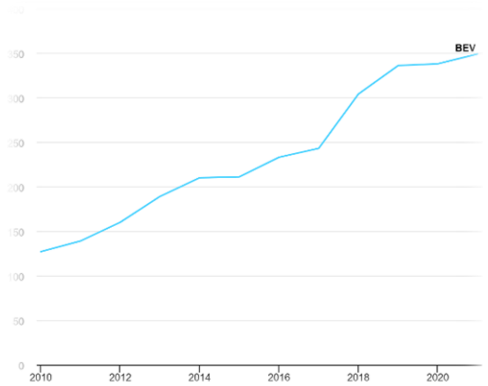
Kellner et al. (2022) emphasize the ongoing extensive pace of the development of more efficient electric motors in the automotive sector to enhance their qualities for use in electric or hybrid electric cars; simultaneously, Moeletsi (2021) highlights that the electric vehicle market still is in its early stages compared to the internal combustion engine market, heavily growing but still limited in production on a global scale, attesting a strong growth potential both in terms of efficiency and marketability.

Electric vehicles (EVs) are indeed a transformative technology in the transportation sector, offering a cleaner and more sustainable alternative to traditional internal combustion engine vehicles. However, the widespread adoption of EVs still face significant challenges. Despite huge growth in recent years, BEVs still represents only 1.2% of the European cars fleet (EEA, 2023).

The choice between EVs, ICE and Hybrid options depends on individual preferences, lifestyle factors, and driving needs. Customers are encouraged to evaluate their priorities, consider the advantages and limitations of each vehicle type, and choose the option that best aligns with their goals and preferences (IEA, 2023).

Less recent studies highlighted various factors that shaped consumer attitudes and intentions towards the early adoption of electric technology. Schuitema et al. (2013) highlighted the role of instrumental, hedonic, and symbolic attributes in consumers' intention to adopt electric vehicles, indicating that perceptions of EV attributes are weakly associated with car-authority identity. Rezvani et al. (2015) emphasize that consumer perception plays a crucial role in the mass acceptance of EVs, underscoring the importance of how consumers view EVs in driving adoption rates.

More recent research instead states that while hedonic and symbolic attributes still are in play, consumer perception of electric vehicles is increasingly influenced by factors such as perceived benefits and risks. Yang et al. (2020) discuss how consumers consider strengths like zero petroleum consumption and little pollution as benefits, while factors like safety considerations and long charging times and supporting infrastructure are perceived as risks, reflecting cost considerations. Additionally, Sovacool et al. (2019) find that willingness to adopt EVs is associated with performance features, perceived benefits of driving an electric vehicle, and policy support for EV promotion.



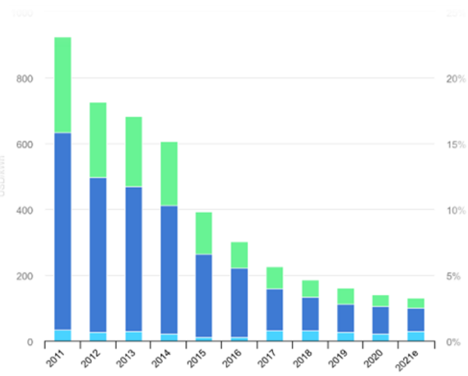


Figure 3 (left) – BEV range increase 2010-2022 (IEA 2023)

Figure 4 (right)– Lithium Battery Costs (IEA 2023)

Improving benefits such as the increased efficiency of electric vehicles (in terms of range), coupled with the decline in battery prices, as highlighted in Figures 3 and 4 (IEA data), have shifted the comparison with internal combustion engine (ICE) vehicles from a somewhat symbolic-hedonistic standpoint to a more direct assessment in terms of performance.

Overall, a combination of supportive policies, technological advancements, infrastructure development, consumer awareness, cost considerations, and industry commitments played a key role in influencing the growth of electric vehicles globally (IEA, 2023). Consumer attitudes, perceptions, and knowledge still significantly influence the adoption of EVs. Studies by Rezvani et al. (2015) and Abbasi et al. (2021), emphasize the influential role of factors such as consumer knowledge of the environmental impacts of driving cars, experiences with vehicles, and familiarity with EVs in shaping preferences for EV adoption. Low awareness levels about EVs, emerge as a key factor hindering adoption intentions, presenting challenges in increasing overall adoption rates.

This attests to the importance of awareness and acceptability, and in general of a 'user focus approach', in the implementation of sustainable policies and the dissemination of sustainable innovations. With the increasing diffusion of technology and growing awareness, biases are dismantled, and market growth becomes evident. GEVO 2023 highlights that in countries with more developed markets, notably China but also the UK, despite reductions in subsidies for the purchase of Light Duty Electric Vehicles (EVs), the market growth rate has continued to rise, indicating the level of maturity achieved in the EV market.

3.1.2 Industrial & Market Dynamics

The rise of electric vehicles is significantly impacting various aspects of the automotive industry to the point that EVs are considered a disruptive innovation that is reshaping the traditional car market and value chain (Shim et al., 2018). The disruptive effect of electric vehicles on the market is acknowledged, leading to paradigm shifts that create new opportunities for firms to capture value in the industry as well as it poses a threat and a challenge to incumbents (Llopis-Albert & Rubio, 2021).

ICE technology has historically dominated the automotive industry and has a well-established infrastructure for manufacturing, distribution, and servicing. However, the transition towards EV technology is gaining momentum, pushed by the highlighted factors such as environmental concerns, government regulations, and technological advancements (Cao et al., 2019).

While EV technology may simplify certain aspects compared to ICE technology in terms of mechanical components and maintenance, it introduces new complexities related to battery systems, charging infrastructure, and supply chain management. Automakers shifting from ICE to EV technology encounter challenges in retooling production lines, training staff, and adapting to new supply chains (Cao et al., 2019; Rhun et al., 2022). The prevailing pattern suggests a shift in the upcoming vehicle generation, transitioning from the consolidated "unibody" design characterized by high production volume and low flexibility, to modular designs with medium to high production volume and increased flexibility (Pandremenos. 2009). As highlited by Pandremenos et al (2009), since its early adoption, EV technology suggested a shift in the upcoming vehicle generation, transitioning from a consolidated ‘unibody’ design carachterized by high production volume and low flexibility, to a modular design. Modular electric vehicle platforms (MEVPs) have revolutionized the automotive industry by introducing a new product architecture that allows for greater flexibility and efficiency in design and production Lampón (2022). These platforms enable the integration of various components in a modular manner, enhancing the scalability and adaptability of electric vehicles, enhancing the existing trend of technology convergence of the car industry innovation pattern.

industries of modular technologies tend to consist of vertically disintegrated firms, each specializing in different modules of the technology (Pisano and Teece, 2007; Argyres and Bigelow, 2010). In contrast, industries of integrated technologies tend to be comprised of vertically integrated firms, each designing and producing all parts of the technology (Pisano and Teece, 2007). Although the vertical (dis)integration of firms is not necessarily tantamount to the division of labor in an industry, as specialized firms can also participate in industries typically consisting of integrated firms and vice versa, the extent of vertical (dis)integration is an important indicator of the division of labor in an industry.

As indicated in the theoretical literature, sectors engaged in modular technologies generally feature vertically disintegrated enterprises, each specializing in distinct modules of the technology (Pisano and Teece, 2007; Argyres and Bigelow, 2010). Conversely, industries associated with integrated technologies typically comprise vertically integrated firms, each involved in the design and production of all components of the technology (Pisano and Teece, 2007). While the vertical (dis)integration of firms does not necessarily equate to the division of labor within an industry, considering that specialized firms may participate in industries traditionally characterized by integrated firms and vice versa, the extent of vertical (dis)integration serves as a crucial indicator of modularity and the division of labor within an industry.

Enhanced modularity in car design reduces barriers for new entrants by simplifying assembly, lowering production costs, and offering adaptability to changing market dynamics. This approach fosters innovation, allowing new players to introduce unique products and establish agile supply chains. The streamlined development process also enables quicker market entry, empowering new entrants to respond promptly to consumer demands. Overall, modularity acts as a catalyst, making the automotive market more accessible and conducive to innovation for emerging players (Lang et al. 2021).

This trend has particularly resonated with Chinese players entering the market, capitalizing on modular advantages lower entry barrier. The Chinese government has provided substantial support and incentives to the automotive sector, fostering a favourable environment for domestic players to thrive and innovate. The involvement and policies of the Chinese government have indeed played a pivotal role in shaping the dynamics of the automotive industry in China, impacting various aspects such as market joint-venture obligations, technology transfer requirements, and the localization of suppliers (Schwabe, 2020).

Additionally, China's strategic investments in the automotive sector extend to a significant share of resources concerning battery materials, further positioning the country as a major player in the global electric vehicle market. This dual influence underscores the comprehensive approach China has taken to not only regulate but actively participate and invest in key aspects of the automotive industry's evolution (Chen et al.,2018).

Prominent examples of Chinese newcomers in the automotive industry include BYD, achieving 35 percent market share in 2023 (Chinese domestic car market), and Geely Auto, recognized for acquiring Volvo Cars. Xiaomi exemplifies the facilitation of new entrants through modularity and the Chinese industrial landscape (Zhou et al., 2021).

The Chinese electric vehicle market has inevitably ascended as the largest and among the most rapidly expanding markets worldwide, accounting for over half of all electric vehicle sales globally (Kovalchuk et al., 2022). This phenomenon intensifies the pressure on European OEMs to innovate, invest and adapt to the evolving dynamics of the electric vehicle industry (Kovalchuk et al. (2022).

Chinese carmakers have gained a competitive edge by prioritizing the development of smaller, more affordable electric vehicle (EV) models ahead of their global counterparts. This strategy involves vertical integration across the battery and EV supply chains, spanning mineral processing to manufacturing. The focus on cost-cutting, aided by factors like inexpensive labour, manufacturing, and financial accessibility, has led to the production of more economical EV options in China (Zhang et al., 2022). In contrast, European and U.S. carmakers, including early pioneers like Tesla, have predominantly concentrated on larger, luxury models, resulting in a limited availability of affordable options for the mass-market consumer (Perkins & Murmann, 2018).

The European automotive industry's emphasis on upmarket positioning has been a defining factor. Despite the shift towards electrification, European automakers have maintained their focus on upmarket positioning, potentially strengthening their brand image and attracting consumers looking for premium electric vehicle options (Pardi, 2021). Furthermore, European automakers have been pioneers in lightweighting initiatives within electric vehicle design. By integrating lightweight materials and innovative design approaches, European automakers can achieve greater ranges for electric vehicles at a similar cost or with smaller batteries and motors, ultimately improving the efficiency and performance of their EV models (Remigio-Reyes et al., 2022). Ultimately, the ability of European automakers to compete effectively against Chinese counterparts in the EV sector will hinge on their capacity to innovate, adapt to changing market demands, and leverage their existing strengths in the industry.

In conclusion, the rivalry between Chinese and European carmakers has stimulated innovation towards sustainability, with a focus on eco-friendly practices, responsible innovation, and the advancement of green technologies (Min et al., 2021). Both regions have made notable advancements in embedding sustainability into their business models and product offerings, their emphasis on sustainable innovation capability and green technology innovation has been instrumental in fortifying corporate sustainability and economic growth (Xu & Bai, 2019; Zhu & Zou, 2022).

3.1.3 Stated Policy feasibility

Targets and ambitions for clean energy technology deployment are often challenging to achieve, but the momentum for Electric Vehicles (EVs) suggests a positive trend towards accomplishment. The transition to clean energy technologies, including EVs, is gaining traction globally. Research indicates that countries with strong cleantech sectors are investing in green energy as a stimulus, leading to effective short- and medium-term outcomes (Kuzemko et al., 2020). A targeted approach, as the EGD is, to addressing clean energy technology challenges can significantly expedite progress is well-supported by research in the field. Studies have indicated that focusing on specific areas of improvement and implementing targeted solutions can lead to more efficient advancements in clean energy technologies (JANG et al., 2022).

In the case of the EGD the main target of the green mobility program is the reduction and subsequent elimination of emissions generated by transportation and mobility through the phasing out of internal combustion engines.

To assess the feasibility of the goals set by global institutions, the IEA-GEVO 2023 develops three different scenarios or pathways for analysing and projecting future developments in the transportation sector and energy systems.

- STEPS: stated policies scenario (more conservative) is designed to provide a sense of the prevailing direction of energy system progression, based on a detailed review of the current policy landscape.
- APS: announced pledged scenario (less conservative) takes into account the policies and measures that have been officially communicated by governments but may not yet be fully implemented. E.g. APS assumes countries in the COP 26 declaration will achieve 100% zero-emission vehicles despite lacking supportive policies.
- NZE: net zero emission (by 2025) scenario

It provides insights into the potential outcomes (if correctly deployed) of these scenarios and their impact on energy systems and emissions trajectories. The difference between STEPS and APS is referred as ‘implementation gap’ between policies implemented and measures required, while the difference between APS and NZE highlights the “ambition gap” that needs to be closed to achieve the goals under the 2015 Paris Agreement (IEA, Global EV Outlook 2023).

As observed by the IEA – GEVO 2023 the projected sales shares of EVs based on stated policies and market trends are now coming close to country stated ambitions for EVs.

In Europe in particular, the EV sales share across all modes is 55% in 2030 in the STEPS. In the APS, Europe has a combined EV sales share of over 60% in 2030 which is in line with the global trajectory in the NZE Scenario. China instead surpassed expectations reaching its target of 20% new energy vehicle sales in 2025 three years ahead of time exceeding expectations, and despite a gradual reduction in EV subsidies since 2017. The sales share of electric cars and vans reaches almost 45% by 2025 in the STEPS, and over 60% in 2030(IEA, 2023).

3.1.4 Environmental Implications

From an environmental standpoint, the advancement of EV technology in the transportation sector brings forth two primary benefits, namely Emission Reduction and Oil Displacement. EV technology, noted for its environmental friendliness by not emitting harmful gases or exhaust pollution during operation (Liu et al., 2020), contribute significantly to emission reductions and oil displacement, as they eliminate the use of fossil fuels and tailpipe emissions (Knobloch et al., 2020).

The increasing number of electric vehicles (EVs) is expected to decrease the reliance on oil, currently constituting over 90% of the total final consumption in the transportation sector. As highlighted in figure 4 by 2030, the anticipated global EV fleet is projected to displace over 5 million barrels per day (mb/d) of diesel and gasoline in the STEPS scenario and nearly 6 mb/d in the APS scenario, a significant increase from the 0.7 mb/d recorded in 2022.

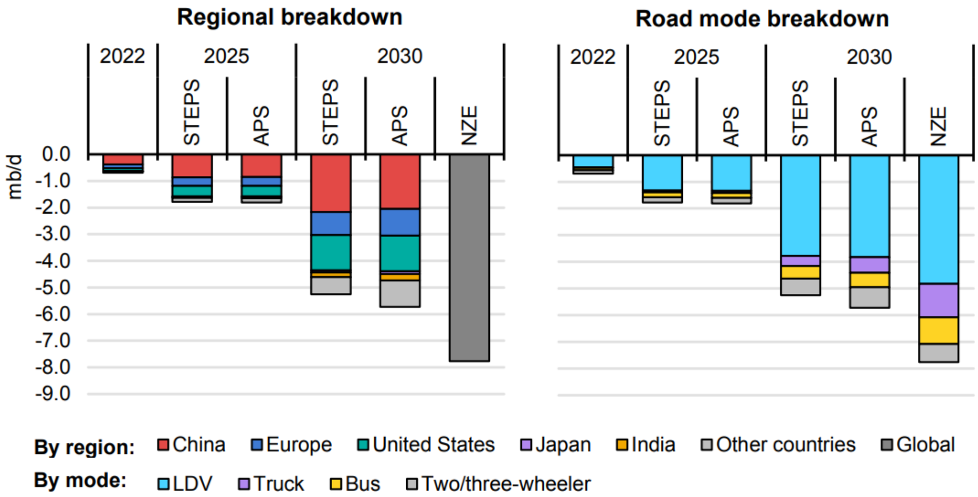


Figure 5 - Oil displacement by region and mode, 2022-2030 (IEA, 2023)

As per today the global oil consumption is stated to be slightly under 100 mb/d with an estimated increase to 106.6 million barrels by 2030 ("Treatment of oil production wastewater by membrane bioreactor", 2022). According to the data provided by the IEA, the STEPS scenario, the more conservative one, would result in a percentage decrease by 2030, leading to an approximately 5% reduction in oil consumption. The reduction would instead reach 7.5% by following the NEZ projection.

Regarding Emission Reduction in 2022, electric vehicles (EVs) contributed to a net reduction of approximately 80 million metric tons (Mt) of greenhouse gas (GHG) emissions on a well-to-wheels basis. As the EV fleet expands, it is anticipated to further decrease GHG emissions on a well-to-wheel basis up to 2030. The net GHG benefit of EVs escalates over time, particularly as the electricity sector undergoes decarbonisation. In the STEPS scenario, the global average GHG intensity of electricity generation and delivery is projected to decrease by 28% from 2022 to 2030, and by 37% in the APS scenario as shown by Figure 5 (IEA, 2023).

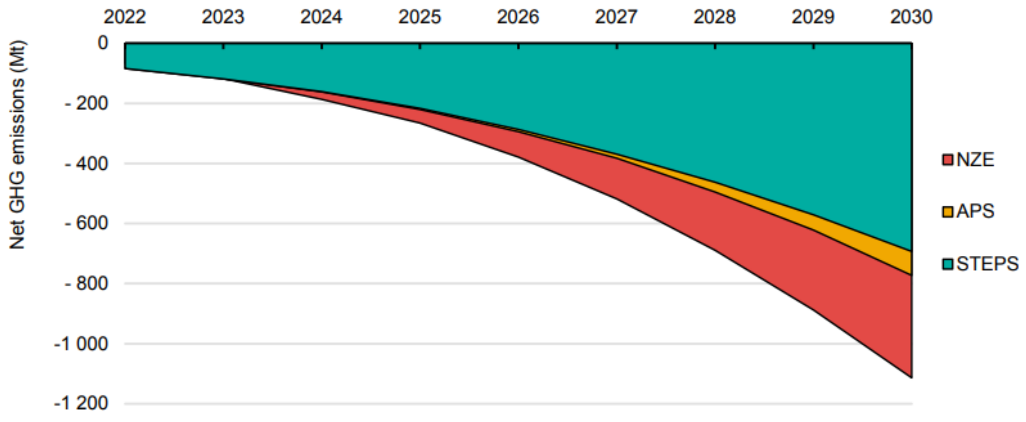


Figure 6 - Net avoided GHG emissions from EV deployment by scenario 2022-2030 (IEA, Global EV Outlook 2023)

In the STEPS scenario, it is projected that by 2030, electric vehicles (EVs) will prevent approximately 700 million metric tons of CO2-equivalent greenhouse gas (GHG) emissions. Despite an anticipated 290 million metric tons CO2-equivalent emissions from electricity production for the EV fleet in 2030, this is offset by the avoidance of 980 million metric tons CO2-equivalent emissions that would have been generated by an equivalent internal combustion engine (ICE) vehicle fleet.

However, when analyzing the statement 'The net GHG benefit of EVs escalates over time, particularly as the electricity sector undergoes decarbonisation,' we encounter the first real obstacle in the environmental sustainability of EVs, namely, dependence on the energy sector.

While EVs have the potential to reduce greenhouse gas emissions and reliance on fossil fuels, their sustainability is intricately linked to the energy sources used for charging (Skrúcaný et al., 2019).

The environmental sustainability of EVs is not only influenced by the energy sources used for charging but also by the life cycle assessment of components like lithium-ion batteries (LIBs) (Dai et al., 2019; Yang et al., 2022). The production and disposal of LIBs have environmental implications that need to be considered to ensure the overall sustainability of EVs. Investment choices in the electricity sector can therefore constrain or enable the transition towards electrical mobility. Investments in clean and renewable energy sources are essential as they positively contribute to the environmental sustainability of EVs by reducing the carbon footprint associated with electricity generation (Esmaeili et al., 2022). Conversely, reliance on conventional and fossil fuel-based energy sources can hinder the overall benefits of electric mobility, perpetuating environmental concerns and limiting the potential for a greener transportation system (Zhuge et al., 2019).

Figure 7 - Life cycle CO2 emissions for vehicles and fuel types (EEA, 2020)

Moreover, as highlighted by Figure 6 contained in The European environment — state and outlook 2020: knowledge for transition to a sustainable Europe (SOER 2020). On a well-to-wheel approach the increase in energy demand stemming from a hypothetical fully electric road transportation sector could result in an overall rise in CO2 emissions.

The trade-off in energy requirements within the transition from Internal Combustion Engines (ICE) to Electric Vehicles (EV) involves a natural increase in electricity demand coupled with a reduction in fossil fuel consumption. Despite EV technology being more energy-efficient in terms of conversion, the energy sector will bear an additional burden (Bugaje et al., 2021). The IEA (2023) estimates that in 2022, the global EV fleet consumed approximately 110 terawatt-hours (TW/h) of electricity, roughly equivalent to the entire energy demand of the Netherlands. Projected electricity demand for EVs is expected to surpass 950 TW/h in the STEPS scenario and around 1,150 TW/h in the APS scenario by 2030, contributing to 3.2% and 3.8% of the global energy demand, respectively (Global EV Outlook, 2023).

While the literature acknowledges electricity demand more as a challenge rather than a burden since the concept that enhanced energy conversion efficiency by electric vehicles (EVs) can contribute to a more sustainable management of energy resources is well-established (Zhang et al., 2019), another important issue that is often recognised is the environmental impact of Batteries.

EV batteries pose environmental challenges across their entire lifecycle. The extraction of raw materials such as lithium, cobalt, and nickel for battery production can lead to habitat disruption and deforestation (Thompson et al., 2020). The energy-intensive manufacturing process, especially for lithium-ion batteries, contributes to greenhouse gas emissions (Pagliaro & Meneguzzo, 2019). Limited recycling infrastructure for complex batteries results in improper disposal and the release of hazardous materials (Chen et al., 2020). Moreover, the reliance on rare earth elements in certain batteries raises concerns about environmental degradation and long-term sustainability (Eftekhari, 2019). Efforts are underway to tackle these challenges. Research on lithium-ion battery recycling underscores the significance of designing for efficient recycling processes (Thompson et al., 2020). Circular economy approaches are being explored, where batteries are reused in energy storage systems and eventually recycled to reclaim valuable components (Pagliaro & Meneguzzo, 2019).

The potential of lithium-ion batteries in designing environmentally friendly electric vehicles underscores ongoing advancements in electrode materials and charging capacities, indicating a trajectory towards more sustainable battery technologies (Sonika et al., 2023). Efforts are underway to tackle the challenges associated with battery technology. Studies on the second life of lithium-ion batteries for off-grid solar-powered systems demonstrate the potential for repurposing batteries beyond their initial use, contributing to sustainable energy solutions (Falk et al., 2020).

3.1.5 Barriers and Lock-in Effect

As electric vehicle (EV) technology continues to gain momentum, it brings forth not only promising environmental benefits but also a spectrum of socio-economic implications. Among these, the fossil fuel lock-in effect and its subsequent drawbacks such as potential job loss and demand for substantial infrastructural development stands out as the main barrier.

The fossil fuel lock-in effect is a phenomenon where existing infrastructure, investments, and policies are heavily reliant on fossil fuel technologies, creating a barrier to the adoption of more sustainable energy sources like electric vehicles (EVs). Factors contributing to this resistance include economic interests, existing employment structures, and established supply chains deeply rooted in the fossil fuel industry (Ueckerdt et al., 2021).

Liquid fuels from fossil fuel sources have a high energy density, are comparatively affordable, relatively straightforward to transport and manage, and benefit from an established infrastructure (EEA, 2021). On the other hand, the development of charging infrastructure for EVs requires a significant investment, which can be sustained through a combination of private and public sources, depending on specific circumstances and policy frameworks (Santos & Davies, 2020). The availability of charging infrastructure is vital for the large-scale adoption of EVs, underscoring the importance of strategic investment (Straka et al., 2020).

The rapid development of EV technology and the subsequent increase in charging demand are posing challenges to the stable operation of distribution networks, highlighting the disruptive impact of EVs on energy infrastructure. The integration of EVs into the energy ecosystem requires a holistic approach to address the evolving dynamics of energy consumption and distribution (Ma et al., 2023), it not only impacts the energy sector but also necessitates a comprehensive understanding of user behaviour and energy consumption patterns to optimize charging network design (Nguyen & Schumann, 2020).

The transition to EVs also raises concerns about potential job displacement and the need for estimating the employment impact of charging infrastructure supporting transportation electrification (Ke et al., 2022).

CLEPA, the European association of Automotive Suppliers provides a report in which it seeks to assess the potential job loss generated by an EV-only transition.

The transitions assessment underscores the crucial role of electrification in aligning with the objectives of the Paris Agreement. However, it also reveals potential employment risks in the powertrain sector. Forecasts indicate a net loss of 275,000 jobs (-43%) until 2040, despite the creation of 226,000 new jobs in electric vehicle (EV) powertrain production. Notably, if Internal Combustion Engine (ICE) powertrain components are phased out by 2035, an estimated 501,000 auto supplier jobs may become obsolete, with 70% (359,000) at risk between 2030-2035. To mitigate these impacts, a mixed technology approach, incorporating renewable fuels, emerges as a potential solution, offering a 50% CO_2 reduction by 2030 while preserving jobs and creating additional value (CLEPA, 2021).

Ultimately, the transition to electric vehicles (EVs) can lead to a reduction in tax revenue generated from fossil fuels, such as gasoline and diesel, impacting government budgets (Moosavian et al., 2021). The potential decrease in fuel tax revenues due to the rise of EVs underscores the need for governments to explore alternative revenue sources or adjust existing tax structures to ensure fiscal sustainability (Zhao et al., 2020).

The fuel lock-in effect can have significant implications on political opinion, potentially hindering sustainable development efforts. Factors contributing to this can lead to divergences in

political and public opinions. This divergence creates a movement that challenges sustainability initiatives, contradicting the overarching goals of environmentally-friendly practices. The risks associated with transitioning to greener alternatives can trigger resistance, especially when considering the economic and social implications of such shifts (Hickel, 2019).
Additionally, the role of media distrust in shaping opinion formation is crucial to consider in the context of sustainable development. This lack of trust can contribute to misinformation and influence public attitudes and behaviours, potentially hindering support for sustainable practices (Ternullo, 2022).

3.2 Alternative Fuels

Alternative fuels have emerged as a promising alternative to fossil fuels due to their potential to reduce greenhouse gas emissions and combat climate change (Jeswani et al., 2020). Among the biofuels, biodiesel, bioethanol, and bio-methanol are considered prominent alternatives for internal combustion engines (Niculescu et al., 2019). These biofuels, derived from living materials, offer a renewable energy source compared to fossil fuels like coal, oil, and natural gas (Mansour & Elshafei, 2022). In the realm of alternative fuels, hydrogen has also gained attention, particularly in the aviation and aerospace sectors, as it offers stable fuel prices, reliability, and can be sourced from various channels, reducing dependence on fossil fuels (Baroutaji et al., 2019).

Hydrogen (Hydrogen Fuel Cells): Hydrogen fuel cells, known for their zero emissions, rapid refueling, and long driving range, show promise as a high-efficiency future fuel (Sharma et al., 2021). However, challenges such as a limited hydrogen infrastructure, energy-intensive production, storage difficulties, and high costs hinder their widespread adoption (Solomon, 2023). While hydrogen fuel cells have the potential to revolutionize energy scenarios, the absence of a comprehensive infrastructure remains a critical hurdle (Peters et al., 2021).

Biofuels (Biodiesel, Ethanol): Biofuels have gained significant attention due to their potential compatibility with existing infrastructure. Drop-in biofuels, such as those discussed by (Dyk et al., 2019), are considered fully compatible with the current petroleum infrastructure. This compatibility extends to the existing liquid fuel infrastructure, including fuel engines, refinery equipment, and transportation pipelines (Wang et al., 2020).

*Natural Gas (Compressed Natural Gas - CNG, Liquefied Natural Gas - LNG) & Propane (Liquefied Petroleum Gas - LPG):*LPG, LNG and CNG, as alternative fuel sources, share similarities in their advantages and limitations. Both Natural gas and LPG fuelled vehicles are known to have low particle number and mass emissions, indicating a positive environmental impact compared to traditional gasoline vehicles (Lähde & Giechaskiel, 2021). However, challenges such as methane leakage concerns, dependence on fossil fuel extraction, limited vehicle models, and infrastructure availability still need to be addressed (even though the effort needed are limited compared to EVs or Hydrogen) to maximize the potential of natural gas as a sustainable transportation fuel (Trivedi et. al.,2020).

Synthetic Fuels (e-Fuels): These fuels are produced using renewable energy sources, making them sustainable and environmentally friendly. Additionally, e-Fuels are compatible with existing infrastructure, which facilitates their integration into current energy systems (Dobrovolsky & Sorokin, 2021). However, there are limitations associated with e-Fuels. The production process is energy-intensive, which can lead to higher costs compared to traditional fossil fuels. Moreover, scalability challenges exist, which may hinder the widespread adoption of e-Fuels as a mainstream energy source (Dobrovolsky & Sorokin, 2021).

In summary, it emerges that concerning Biofuels, e-Fuels, natural gas, and LPG, there is generally good synergy with current engine technology, particularly with existing infrastructure. This would thus allow for a relatively straightforward circumvention of the lock-in effect. On the other hand, despite achieving better (albeit variable among them) environmental results than fossil fuels, they are still unable to compete with those recorded by electric vehicles (EVs).

Conversely, a different scenario emerges for hydrogen. Despite yielding excellent environmental results and equally being considered zero-emission, it requires an infrastructural effort somewhat surpassing that demanded by electric vehicles and is therefore subject to a similar degree of susceptibility to the lock-in effect. Hydrogen technology is more likely to have a significant impact on heavy transport and aviation rather than in the car industry, mainly due to the fact that the liquefaction of hydrogen significantly increases its energy density, making it suitable for large-scale transport by road tanker, planes or ship, particularly for long distances where pipelines are not economically feasible (Wolfram et al., 2022).

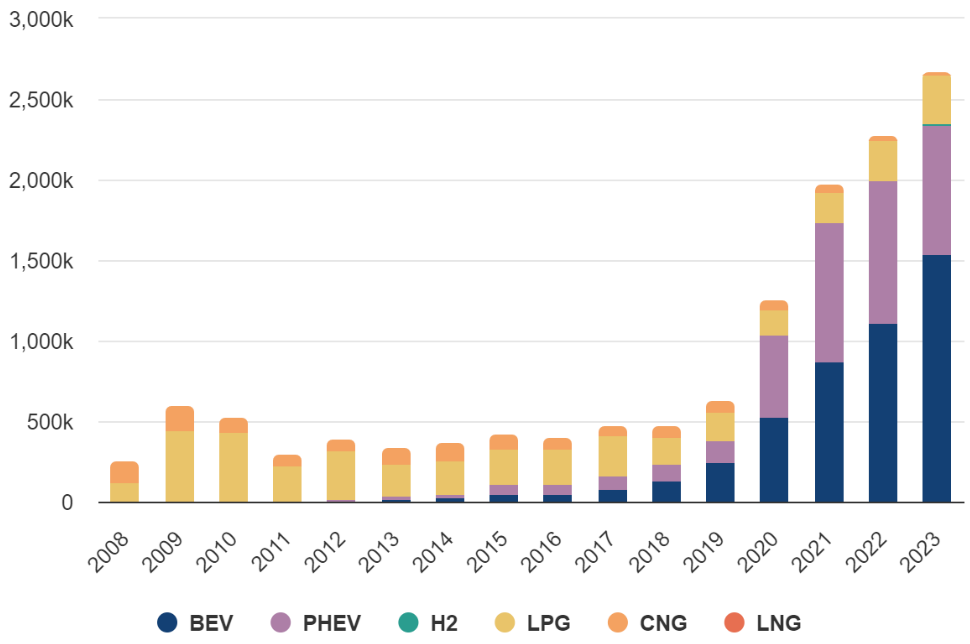


Figure 8 - Number of newly registered alternative fuel vehicles EU (IEA, 2023)

What truly hinders the adoption of alternative fuels and their consideration as a viable alternative, especially when compared to Electric Vehicles (EVs), is that despite being more or less established technologies (in time terms), they have never been able to carve out a significant market share. The disruptive impact caused by the entry of EVs into the market is not comparable to that of other alternative fuels. Consequently, manufacturers have never truly invested in their respective technologies. As evident in Figure 7, the gap between the growing market shares of electric (including PHEV) seems realistically challenging to bridge.

From the perspective of OEMs, the investments made by automotive companies in EV technology and the numerous car models introduced to the market now represent a clear, and hardly reversible, step toward an electric future for automobiles. However, given the current limitations of EVs in the heavy-duty sector, as well as in aviation and maritime fields, alternative fuels, and specifically hydrogen, being zero-emission, present a potential source of sustainability that is being, and will continue to be explored (Manoharan et al., 2019).

3.3 Shared Mobility

Shared mobility encompasses various forms of shared transportation services, such as shared rides, bikes, cars, and public transit, all integrated into a unified interface like a smartphone app or website. This approach allows for short-term access to shared vehicles based on users' specific requirements and convenience. Efforts have been made to create taxonomies that capture the relationship between digital technology, transportation, and the sharing economy (Machado et al., 2018).

Shared mobility has been shown to have a transformative impact on urban areas by improving transportation accessibility while reducing the reliance on personal vehicle ownership and driving. It is closely linked to the concept of Mobility as a Service (MaaS), where various modes of transportation are seamlessly integrated into a single platform for users. The idea behind shared mobility is to provide access to vehicles like cars, bicycles, or scooters as needed, rather than owning them outright (Fioreze et al., 2019).

The integration of Electric Vehicle (EV) technology with shared mobility yields positive outcomes, particularly in fostering urban sustainability (Hossain et al., 2022). Pivotal aspects of their synergic relationship include the reduced operational costs and the leveraging of EVs advanced technologies, such as app-based platforms and fleet management systems., creating a conducive environment for the coalescence of both technologies.

Shared mobility operators benefit from the cost-effectiveness of EVs and reduced maintenance, enhancing the economic viability of shared electric transportation.

Research also indicates that EVs offer better performance in short travels and urban environments (Milligan et al., 2019). This is particularly relevant as the urban environment poses unique requirements better exploited by EVs such as low speed efficiency, regenerative braking and quiet operation. Regenerative braking, a key technology in EVs, not only enhances energy efficiency but also contributes to extending the vehicle's range, reducing fuel consumption, and minimizing emissions (Vasiljević et al. 2022).

The integration of app-based platforms and fleet management systems with Electric Vehicles (EVs) is a strategic move that aligns with the market shift towards electromobility in shared mobility services (Turoń et al., 2020). This transition is part of a broader trend in the automotive industry, where traditional ownership models are giving way to multimodal and shared mobility services, emphasizing convenience and sustainability (Vermesan et al., 2021).

Simultaneously, the harmonization of EVs with regional incentives and policies further strengthens the collaboration, promoting a supportive atmosphere for sustainable and shared urban mobility solutions. In uniting shared mobility and EV technology, cities can cultivate transportation solutions that are not only economically efficient but also environmentally

sustainable. This synergistic approach supports urban development initiatives focused on reducing congestion, enhancing air quality, and advancing overall sustainability.
As per statista data The Global Shared Mobility market is projected to achieve a revenue of €1,516.00 billion by 2024, with an estimated annual growth rate of 3.45% (CAGR 2024-2028). This growth trajectory is anticipated to lead to a market volume of €1,736.00 billion by the year 2028.

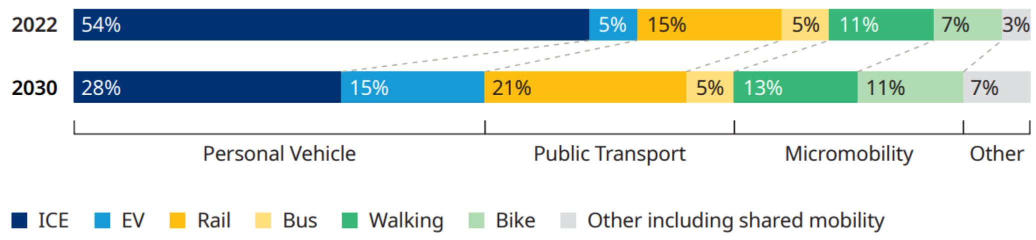


Figure 9 - Oliver Wayman modal mix estimation (Wayman, 2023)

From figure 8 extracted by Wyman report - Shared Mobility's Global Impact (2023) we can observe that the projected impact of shared mobility might seem restricted even though its numbers will be more than doubled between 2022-2030. The real impact of shared mobility relies in its synergy with the public transport system. Shared mobility plays a crucial role in complementing public transport systems by providing solutions for last-mile connectivity, thereby bridging gaps in transportation networks. Becker et al. (2020) highlight that shared mobility services, predominantly operating in urban areas, have the potential to extend public transport networks by offering first-and-last-mile connections, thus attracting public transport users and improving overall efficiency and accessibility. Reducing the user reliance on private cars and, as a consequence, traffic congestions.
The impact of shared mobility therefore requires a solid public transport system and shows its limitations in less developed urban areas. Shared mobility services are often concentrated in wealthier neighbourhoods that already have good access to public transit, indicating potential disparities in service distribution (Boeing 2019).
The younger demographic generally holds positive views on shared mobility and is open to using such services in the future. The trajectory of shared mobility may be significantly amplified in the future by ongoing technological advancements and a heightened societal acceptance. (Goralzik et al., 2022).

3.4 Alternative to car Ownership

The rise of car subscriptions represents a contemporary shift in vehicle ownership paradigms, offering a flexible alternative to traditional models by providing users with on-demand access to vehicles without long-term commitments and associated hassles. This shift is supported by the trend of growth in the for-hire vehicle market, particularly in mid-sized and large cities, among younger individuals, and wealthier households (Conway et al., 2018). The impacts of this shift include a decrease in the need and demand for personal cars, the rise of large fleet services like car subscriptions, and lower maintenance needs, which are expected to significantly impact the growth of domestic automotive companies and increase competition in international markets.

Started by non-OEMs companies like the German SIXT+, Finn or Enterprise. Car companies like Volvo, Porsche, Mercedes, Hyundai and KIA are now entering and exploring the business since the start of the decade (Fortune, 2023).

By deviating from traditional approaches and embracing new business models, companies can effectively navigate the evolving landscape of electric vehicle ownership and subscription services (Chen & Pérez, 2018). In this scenario, as stated by Mercedes, car subscription model can serve as a consumer’s flexible entry into the electric vehicle market, spreading awareness, as well as a mean to encounter changing consumer’s needs towards more flexible solutions.

As we can observe although car subscription models still represent a relatively expensive option for consumers (Conway et al., 2018) the young age of the market and future exploitation of economies of scale suggest improvement in this regards.

According to 2023 Fortune report, the global vehicle subscription market size was valued at $2.11 billion in 2021 and is projected to grow from $3.38 billion in 2022 to approximately €172.47 billion by 2029.

The growth underscores the industry's response to a dynamic and shifting automotive landscape. The shift towards alternative car ownership models is further supported by the trend of purchase being replaced by effective use, restrictions on car ownership imposed by municipalities and the emergence of new mobility models in the automotive sector (Fronteli & Paladini, 2022).

4. Long Term Disruption

4.1 Disruptive Innovation Ecosystem

4.1.1 Short-term and Long-term Player's orientation

The automotive industry exemplifies the self-expanding nature of value within capitalism and the global ecological challenges it poses. This industry embodies Unruh's concept of 'carbon lock-in,' where early capital-intensive technological decisions establish a reinforcing loop of product technology, production methods, and business structures (Crossa, 2021; Mattioli et al.2020; Unruh. 2000).

In this scenario, large automotive manufacturers are bound to prioritize short-term profits due to various factors. The competitive nature of the industry compels companies to meet quarterly financial targets to satisfy shareholders and investors. This pressure from the stock market can lead to a focus on immediate profitability over long-term sustainability and research and development (Grisales et al., 2020). High capital investments in manufacturing facilities and R&D also drive companies to prioritize short-term gains to meet financial obligations and demonstrate stability to investors. Economic uncertainties and fluctuations in consumer demand further push companies towards short-term profitability as a strategy to navigate volatile market conditions (Horobet et al., 2021).

This emphasis on short-term gains may result in cost-cutting measures that compromise long-term strategic initiatives, sustainability efforts, and innovation (Grisales et al., 2020).

Start-ups, with their inherent characteristics such as flexibility, entrepreneurial culture, lack of legacy constraints, customer-centric focus, risk-taking mind-set, access to talent, and lean operations, are often better positioned for long-term orientation suitable for continuous innovation compared to larger, more established companies. Research by Ghezzi & Cavallo (2020) highlights how start-ups operate in dynamic environments and utilize strategic sensitivity, resource fluidity, and leadership unity to establish new value systems and business models, enabling them to navigate through markets effectively.

Unlike traditional industry players, start-ups are not bound by the need to maintain the status quo, allowing them to introduce innovative strategies and technologies that can lead to industry-wide transformations (Ludwig et al., 2022) Additionally, start-ups are highlighted for their ability to quickly respond to market changes, adopt innovative strategies, and commercialize new knowledge for profit growth (Hou et al., 2019).

4.1.2 Coexistence of start-ups, traditional industry players and Big Tech Giants in the mobility and automotive sector

The reduction of entry barriers and the disintegration of value chains, fostered by the disruption features of EV technology, have opened the doors of the automotive and mobility industry to new players and start-ups. The automotive industry has undergone a significant transformation (Jankovic-Zugic et al., 2023). Connectivity and tech integration emerged as a major trend, transforming modern vehicles into highly intelligent computers on wheels (Sterk et al., 2022), highlights the increasing importance of data and connectivity in the automotive sector.

Conversely, the demand for connectivity and integration has led car companies to acquire a diverse set of competencies, gradually transforming them into entities that resemble tech and software companies. The increasing importance of technologies such as IoT (Internet of Things), AI (Artificial Intelligence), Automated drive and software-driven functionalities in vehicles is reshaping the traditional automotive landscape, pushing companies to expand their skill sets beyond traditional manufacturing and engineering.

In the attempt to navigate new mobility industry requirement incumbents, have two main choices: *Separate & Divest* or *Aquire.* (Turienzo & Lampón., 2022).

Separate & Divest/Restructure – this option will likely become one of the most widespread, as it involves maintaining a focus on the most profitable core activities while separating business areas that require profound transformation.

Acquire - in cases where developing new competencies internally is excessively costly or complex, suppliers may enter new market segments through the direct acquisition of specialized players.

In the second case, OEMs and start-ups engage in cooperative ventures to capitalize on each other's strengths, fostering innovation and technology integration in the rapidly evolving mobility sector. Start-ups, benefit from OEMs' market presence, gaining access to broader distribution channels. OEMs, in turn, leverage start-ups' innovations to enhance their product portfolios, forming strategic partnerships through joint ventures or investments. This collaboration not only supports ecosystem development with mentorship and resources but also facilitates agile responses to market changes, regulatory compliance, and the creation of customer-centric solutions that cater to diverse mobility needs.

This collaborative approach aligns with 's study (Bettenmann, 2023), which emphasizes how engaging with start-ups through corporate accelerators can enhance innovativeness within established companies. Furthermore, the study by Zhang et al. (2023) sheds light on how government subsidies can facilitate cooperation between OEMs and independent remanufacturers, enabling technology transfer and joint ventures in the automotive sector.

The involvement of big tech companies in the mobility sector has been a significant development in recent years. Tech giants such as Alphabet (Google), Apple, and Amazon have been actively shaping the future of auto mobility by developing car-specific interfaces, self-driving technologies, and establishing partnerships with traditional automakers (Hind et al., 2022).

The entry of big tech companies into the mobility sector is part of a broader trend where these firms are expanding their reach into various industries beyond their traditional domains (Bethlendi & Szőcs, 2022). This diversification of services and industries by big tech companies reflects their ambition to drive innovation, capture new markets, and capitalize on emerging trends.

While start-ups bring innovation and agility, big tech companies possess the financial muscle and technological prowess to disrupt the automotive sector significantly.

Although, much like start-ups, big tech companies entering the automotive and mobility sector are not bounded to the traditional car-culture consumption system as defined by Mattioli et al (2020). Their strategic involvement indicates a forward-looking approach, suggesting that they are less invested in perpetuating a future dominated solely by private car ownership Instead, they seem poised to shape a mobility landscape that transcends conventional paradigms, emphasizing innovation, sustainability, and transformative user experiences (Hind et al., 2022).

As we navigate this dynamic landscape where incumbents, big tech, and start-ups converge in the automotive and mobility sector, two ground-breaking trends emerge—Mobility as a Service (MaaS) and Autonomous Drive. The coexistence of these key players is catalysing a futuristic paradigm shift, one that envisions a seamlessly integrated and autonomous mobility ecosystem.

In this chapter, we will delve into the transformative potential of MaaS and Autonomous Drive, exploring their synergies and individual impacts on the future of transportation.

4.2 Autonomous Drive

Autonomous drive, now emerging in the car industry, has historical roots reaching back to the early 20th century, marked by experimental endeavours and concepts that evolved over the decades. While its early applications in agriculture in the late 20th century laid the groundwork for autonomous principles (Sáiz-Rubio & Rovira-Más, 2020), it's the recent convergence of advancements in computing power, artificial intelligence, and sensor technologies that has propelled the tangible realization of autonomous drive capabilities. This synergy not only bridges the historical journey from agricultural automation to vehicular autonomy but also ushers in a transformative reality where the once aspirational idea of self-driving vehicles becomes increasingly viable (Zhang & Shen., 2020).

The development of autonomous driving technology saw significant milestones in the early 2000s, particularly with DARPA launching Grand Challenges to drive progress in autonomous vehicles. These challenges took place in 2004, 2005, and 2007, playing a crucial role in advancing autonomous driving technology (Kabzan et al. 2020). Subsequently, Google became a major investor in autonomous driving technology in 2009, leading to the establishment of Waymo in 2016 (Rahmani et al., 2023). During this period, Tesla introduced advanced driver-assistance features in 2015, a notable step towards autonomous driving capabilities. At the same time, Uber made substantial investments in autonomous research, further fostering the development of self-driving technology. Established automakers such as General Motors and Ford also significantly contributed to shaping the autonomous drive technology landscape, consistently advancing the industry (Rahmani et al., 2023).

As these entities, among others, advanced in their pursuits, the current state-of-the-art in autonomous drive is marked by a convergence of technological sophistication, real-world applications, and a continuous drive towards achieving fully autonomous capabilities. The development of autonomous vehicle systems involves integrating various technologies to create complex systems for commercial autonomous driving projects (Liu et al., 2018). Human factors play a critical role in the sustainable development of autonomous driving technology, emphasizing the importance of usability and biological aspects in the design and implementation of autonomous systems (Cárdenas et al., 2020).

4.2.1 State of The Art of Autonomous Technology

Within the framework of autonomous drive technology, the evolution is delineated by defined levels. The Society of Automotive Engineers (SAE) outlines six levels of Automation (LoA), ranging from no automation (Level 0) to complete automation (Level 5) (Cervera-Uribe & Méndez-Monroy, 2021). LoAs are explained as follows: no automation (0), driver assistance (1), partial automation (2), conditional automation (3), high automation (4), and full automation (5) (Liu, 2019).

As of today the automotive industry predominantly operates within Levels 2 and 3, as vehicles offer advanced driver-assistance features but still require human intervention. At Level 3, vehicles can sense the environment through multiple sensors and drive autonomously but may require human intervention in certain situations.

The impasse stems from the existence of technology capable of achieving higher degrees of automation; however, its implementation hinges on addressing human factors inherent in automated driving. This necessitates striking a balance between the convenience offered by the technology and the associated safety risks. Moreover, transitioning to Level 3 and beyond requires resolving challenges related to the vehicle's autonomy, the interaction between automated vehicles and conventional traffic infrastructure (Lengyel et al., 2020), and the substantial volume of sensory data that demands processing.

4.2.2 Value Added

Autonomous vehicles bring forth a spectrum of benefits, encompassing enhanced safety, positive environmental implications, and improved cost efficiency. Delving into these aspects not only underscores the transformative potential of autonomous drive but also explores its broader societal relevance. This exploration delves beyond technological capabilities, examining the profound impacts that autonomous vehicles can have on safety, sustainability, and accessibility in the realm of modern transportation.

1. Road Safety: The potential to enhance road safety is one of the primary benefits of autonomous vehicles. Equipped with advanced sensors and algorithms, autonomous vehicles have the capability to mitigate human errors, which are a major cause of accidents, leading to a substantial reduction in traffic-related injuries and fatalities. Automated Driving Systems (ADSs) are expected to substantially reduce human-caused road accidents while simultaneously lowering emissions, mitigating congestion, decreasing energy consumption, and increasing overall productivity (Novickis et al., 2021).

2. Environmental Implications: Autonomous vehicles have the potential to significantly contribute to environmental sustainability by optimizing driving patterns, reducing traffic congestion, and advancing electric and shared mobility systems. Research indicates that autonomous vehicles will be a crucial element in the sustainable cities and transport systems of the future (Pettigrew & Booth, 2023).
3. Cost-effectiveness: Research suggests that while the initial costs of implementing autonomous technology are substantial, the long-term benefits can outweigh these expenses. One significant aspect is the improved safety provided by autonomous vehicles, leading to reduced accident-related costs (Tan et al. 2023). Additionally, the optimization of driving patterns in autonomous vehicles can result in fuel savings, contributing to long-term cost efficiency (Prakash et al., 2019). Studies have shown that the investment and manufacturing costs of autonomous vehicles are often lower than the labour costs associated with traditional drivers and delivery personnel, particularly in developed countries with high labour costs (Feng, 2021).
4. Accessibility**:** Autonomous vehicles have the potential to enhance mobility for individuals who face challenges in conventional transportation, such as the elderly or those with disabilities. It could provide a newfound independence and accessibility to transportation services (Cordts et al. 2021).

4.2.3 Autonomous Horizon

Navigating the transformative landscape of autonomous drive technology reveals its impact far beyond the confines of individual vehicles. It's not just about technological prowess; societal implications beckon us to envision a future where the integration of autonomous vehicles not only optimizes transportation but also shapes the design, structure, and dynamics of the cities we inhabit.

The rise of autonomous vehicles heralds significant changes in the transportation industry. A notable transformation is the surge in shared mobility services facilitated by autonomous vehicles, challenging traditional car ownership models. This shift is part of a broader trend where companies transition from merely manufacturing vehicles to offering comprehensive mobility solutions, disrupting urban transportation systems (Beirigo et al., 2018).

Autonomous technology prompts a reimagining of vehicle design, emphasizing passenger experience over driving. Car interiors may evolve into multifunctional spaces—mobile offices, entertainment hubs, or relaxation areas (Parida et al., 2018). As Level 5 driving technologies advance, innovative seating configurations and interior layouts promise significant improvements in occupant comfort and experience (Diederich et al., 2021), aligning with the concept of autonomous vehicles as adaptable spaces for diverse passenger needs.

Considering passenger comfort becomes crucial in autonomous vehicles, incorporating vehicle motion states and physiological characteristics into the design process (Wang et al., 2020). This human-centric approach underscores a shift towards anthropomorphism in autonomous vehicle control, indicating a revolutionary approach in vehicle design.

The potential impacts on urban planning are substantial. Reduced car ownership may lead to pedestrian-friendly cities, green spaces, and improved public transportation (Gavanas, 2019). Repurposing urban spaces designated for parking could foster recreational areas or mixed-use developments, potentially reshaping the urban landscape and driving a suburbanization trend (Kang & Kim, 2019).

The design of autonomous vehicles extends beyond transportation, considering factors like light pollution, pedestrian-friendly urban spaces, and ecological sensitivity (Stone et al., 2019). Societal implications encompass wildlife conservation and environmental sustainability, emphasizing the need to consider impacts beyond urban settings and human safety (Silva & Calabrese, 2021).

Despite the opportunities, concerns exist about the readiness of urban planners to integrate autonomous vehicles into city planning. The autonomous vehicle revolution necessitates a comprehensive understanding of implications for urban spaces, transportation systems, and governance to grasp potential changes in transportation systems and societal dynamics (Szabo, 2020; Porter et al., 2018).

From multifunctional interiors to the reshaping of urban landscapes, the impact extends far beyond the immediate advancements in safety and efficiency. As we embrace this transformative era, it becomes evident that the evolution of autonomous vehicles is not just a technological leap but a profound shift in how we perceive, interact with, and integrate these intelligent entities into the fabric of our societies.

4.3 Mobility as a System (MaaS)

The concept of Mobility as a Service (MaaS) invites us into a paradigm where transportation transcends traditional boundaries. MaaS represents more than a mere technological evolution; it embodies a holistic approach that integrates various cutting-edge technologies, reshaping how we perceive and access mobility.

4.3.1 Concept

Mobility as a Service (MaaS) is a transformative concept that signifies the progression from shared mobility to an interconnected, user-centric network (Xi et al., 2022). This evolution addresses the complexities of urban transportation by integrating various travel modes into a single accessible on-demand service (Xi et al., 2022). MaaS offers a comprehensive solution that goes beyond traditional transportation methods, catering to current and future mobility demands such as intermodality, personalization, on-demand services, and seamlessness (Garcia et al., 2019).

At its core, MaaS converges various cutting-edge technologies to redefine how we approach mobility. Big Data plays a pivotal role, enabling the aggregation and analysis of vast amounts of information related to transportation patterns, user preferences, and real-time conditions. The Internet of Things (IoT) interconnects vehicles, infrastructure, and users, facilitating real-time communication and data exchange. Platforms, often in the form of mobile applications, serve as the orchestrators, providing users with a unified interface to seamlessly plan, book, and pay for a myriad of transportation services.

Mobility as a Service (MaaS) is a concept that integrates various modes of transportation such as buses, trains, rideshares, and more into a single user-friendly platform, aiming to provide commuters with a seamless and interconnected mobility experience (Garcia et al. 2019). This convergence of technologies not only enhances convenience but also promotes sustainability, efficiency, and responsiveness within urban transportation systems (Jang et al., 2020).

The idea of MaaS is centred around bundling mobility services to offer economic, societal, and environmental benefits to future cities (Polydoropoulou et al., 2020). Research has shown that MaaS caters to different commuter preferences, with latent classes divided into public transit-oriented commuters and balanced mode commuters (Kim et al., 2021). This segmentation highlights the flexibility and personalized nature of MaaS offerings.

4.3.2 Reshaping Urban Mobility

To successfully transition from a car-centric culture, Mobility as a Service (MaaS) must establish robust technical foundations. Key elements include seamless connectivity, user-friendly interfaces, advanced payment systems, interoperability between different transportation modes, and secure data sharing to ensure an integrated user experience (Сакульева, 2019). MaaS aims to reduce dependence on private cars, promoting sustainability and offering various travel services in a more sustainable and convenient manner). However, amid the promise of technological advancement within Mobility as a Service (MaaS), concerns arise regarding privacy consideration on personal data. The imperative to safeguard user interests becomes paramount, emphasizing the need for robust measures to protect user data, ensuring transparency, and fostering trust in the MaaS ecosystem (Cottrill, 2020).

MaaS promotes a shift from individualistic private vehicle use towards a more communal perspective, aiming to create a more efficient, user-centric, and environmentally friendly urban transportation system. This paradigm shift is essential for fostering a more interconnected and environmentally conscious approach to transportation (Souza et al., 2019). MaaS represents a transformative force that redefines how individuals access mobility and contributes to the development of sustainable urban mobility solutions. By integrating various modes of transport into a unified service consumed based on passenger needs, MaaS aims to create a more sustainable urban mobility culture.

Mobility as a Service (MaaS) highlight the crucial role of users in transforming their behaviours in embracing shared mobility and reducing reliance on traditional car ownership models. Research has shown that public transport users may be hesitant to switch to MaaS, emphasizing the necessity for strategies to overcome barriers and encourage adoption (González, 2020). Challenges related to the integration of MaaS underscore the importance of collaborative efforts among stakeholders to facilitate the transition and promote shared responsibility in urban mobility practices (Henry et al., 2021).

5. Conclusions

The global automotive industry is facing significant disruption due to key technology-driven trends, first of all EV technology (Bhattacharyya & Thakre, 2020). These trends are reshaping traditional automotive paradigms and challenging established norms (Bhattacharyya & Thakre, 2020).

In this hybrid phase characterized by the coexistence of different design solutions within the automotive sector, however, EV technology has not yet asserted itself as a dominant new design. Acknowledging its potential, we can assert, based on the literature, that its disruption within the market is justified by the so-called technological leapfrogging the rapid adoption of advanced technologies while bypassing intermediate stages of development (Ng & Tan, 2018). Literature emphasise that leapfrogging involves technological accumulation by enterprises, enabling rapid advancement in their respective fields (Guo & Lu, 2021) and the effects of the disruptive force, analysed throughout chapter 3, caused by the advent of electric vehicles in the automotive industry are tangible in this regard.

Enhanced competition, facilitated by reduced entry barriers and the consequent disintegration of the supply chain, has promoted the entry of new players, the acquisition of new competencies, increased investments in developing more efficient solutions, and the growing integration of technologies within the automotive sector. Gains in energy consumption, infrastructure improvement, and greenhouse gas emissions reduction, underscore the disruptive nature of EVs in revolutionizing the transportation ecosystem (Silva et al., 2023).

Parallel to this, it can be observed that progress in a sustainability perspective primarily addresses the environmental sphere, specifically the spectrum related to pollution and emissions, while only partially touching upon the economic and social dimensions, as well as other facets of the environmental dimension such as urban sprawl and the shift of responsibility towards the energy sector in terms of energy consumption.

By 2030, passenger traffic is projected to surpass 80,000 billion passenger-kilometres, marking a fifty percent increase, while global freight volume is expected to grow by 70 percent. The worldwide vehicle count is anticipated to double by 2050 (World Bank, 2017). In a situation where the need for infrastructure implementation, among the many, is seen as one of main obstacles the proposed scenario might means an unbearable effort.

The existence of car-dependent systems in advanced economies impedes the transition to more sustainable modes of transportation (Mattioli et al., 2020). Car ownership is deeply rooted in societal norms –social lock-in effect-, with public transport often associated with a stigma of poverty (Heinonen et al., 2021). The necessity for widespread behavioural change to tackle sustainability issues progresses slowly, with many advanced economies struggling to reduce their reliance on cars (Mattioli et al., 2020).

In conclusion, the advent of Electric Vehicles (EVs) marks a significant leap forward in the automotive industry's journey towards sustainability. While facing challenges and resistance from established norms and vested interests, EV technology has disrupted the sector, prompting a reconsideration of traditional paradigms. The concept of technological leapfrogging, as evidenced in the rapid adoption of advanced EV technologies, has not only propelled the automotive industry into a new era but has also catalysed broader changes in the transportation ecosystem.

As we navigate this hybrid phase of coexisting design solutions, it is clear that the disruption caused by EVs extends beyond environmental benefits. The enhanced competition, reduced entry barriers, and integration of technologies within the automotive sector have ushered in a wave of innovation and efficiency gains.

Looking ahead to chapter 4, while EVs have made substantial strides in addressing sustainability concerns among all three dimensions, it is essential to recognize them as a stepping stone rather than a panacea. The integration and technological convergence within the automotive sector open a window of opportunity to reshape a sector that may have remained dormant within its barriers for too long. The future of mobility envisions a world where private vehicles are no longer at the centre, allowing space for both people and nature to reclaim their domains.

Considering the potential of Mobility as a Service (MaaS) and autonomous driving technologies, it becomes evident that the future of mobility extends beyond merely eliminating vehicle emissions. It involves a fundamental shift in perspective, where synergies between EVs and these emerging technologies become decisive for the future.

The electric revolution, therefore, represents not only a small step towards gradually eliminating vehicle emissions but also a technical synergy that could be pivotal for a more sustainable future and the innovations of tomorrow.

6. Further Research & discussion

The qualitative nature of the measurement employed, grounded in the analysis and application of theoretical frameworks on sustainability, presents a notable limitation. While providing valuable insights into the conceptual and strategic aspects of innovation, the absence of quantitative data constrains the ability to conduct a more pragmatic analysis and assessment of the real-world impact of the innovations discussed, particularly those explored in Chapter 4.

Furthermore, as we paint an optimistic scenario, envisioning the overcoming of obstacles, it is crucial to introduce a dose of realism. The dominance of big tech companies in shaping the long-term future of mobility introduces a complex dynamic. These entities, being profit-oriented, may not always align seamlessly with sustainability principles and the ideals of a circular economy. Understanding the potential conflicts between profit motives and sustainability goals becomes an important area for future research, delving into the strategies and policies required to balance these conflicting objectives.

Additionally, the model of reflection and analysis, particularly concerning the political initiatives addressing sustainability, exhibits certain biases. The framework is predominantly European-centric, and the focus on urban dynamics might not encapsulate the diverse geographical and demographic variations across the globe. A more comprehensive understanding of sustainable mobility requires a nuanced exploration of regional and demographic differences, acknowledging that a universal model for sustainable mobility might be an elusive goal. Future research could therefore explore and adapt the current model to accommodate the intricacies of different geographical and demographic contexts.

In conclusion, while the thesis has provided valuable insights into the theoretical underpinnings and strategic considerations of sustainable mobility, the limitations related to the qualitative nature of the analysis, the profit orientation of major players, and the Euro-centric model call for further investigation. Future research endeavours could bridge these gaps by incorporating quantitative data, exploring the delicate balance between profitability and sustainability, and adapting models to embrace the diversity inherent in global mobility dynamics. Addressing these aspects will undoubtedly contribute to a more holistic and globally relevant understanding of sustainable mobility in the evolving landscape of transportation.

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