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Bibliometric Analysis Presenting the Current State of Scientific Research, Evolution and Management of Sustainability

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ABSTRACT

The concept of sustainability has gained attention in academia, business, and policy, driven by concerns about environmental degradation, social inequities, and economic imbalances. This study analyzes scientific research and the evolution of sustainability, focusing on the automotive industry in management, business, and economics. Conducted from May to August 2023, a bibliometric analysis explores global trends, revealing diverse contributions. It emphasizes the need to enhance industry sustainability, particularly in the automotive sector, a significant contributor to global emissions responsible for ~10% of the greenhouse gas emissions. Regulations for achieving net-zero emissions extend from production to vehicle usage. Despite substantial volume of sustainability-related publications between 1900-2023, a comprehensive understanding of sustainability management practices, especially in specific industries, is underdeveloped indicating a gap between existing research and the practical implementation of sustainable practices, especially within industries such as automotive.

1. Introducing the Problem, Purpose and Objectives of the Study

The burgeoning interest in sustainability across academia, business, and policy realms reflects a global recognition of the urgent need to address environmental degradation, social inequities, and economic imbalances. Within this context, the automotive industry stands as a crucial domain for addressing sustainability concerns, given its significant contributions to environmental degradation through emissions and resource consumption. Herein the transportation sector makes up 16,2% as of year 2016 – while mobility as road transportation sums up to ~12% of the global emissions in 2016 and continues to rise when looking at a timeframe of the last 30 years (Richie, 2020).

The existing body of literature, as evidenced by a bibliometric analysis covering over a century of research, indicates a substantial volume of publications focused on sustainability, yet lacks a thorough exploration of industry-specific practices and their effectiveness.

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Therefore, there is a pressing need for further research to fill this gap and provide insights that can guide the automotive industry towards more sustainable operations. In effect, the problem statement highlights the deficiency in existing literature regarding the comprehensive exploration of industry-specific sustainability practices within the automotive sector, underscoring the need for further research to inform and advance more sustainable operations.

The overarching goal of the bibliometric analysis is designed to delve into the academic landscape surrounding sustainability in the automotive business. The primary objectives are threefold:

1. To explore the academic evolution of "sustainability" related concepts into management, business, and economics areas
2. To identify published works in the field of study, specifically publications focused on management of sustainability in the automotive sector
3. To provide an analysis report presenting the evolution of publications, the most representative organizations, and regional differences

This study underscores the critical imperative to enhance sustainability within the automotive sector, given its pivotal role in global emissions. By elucidating gaps in current understanding and delineating avenues for future research, this analysis seeks to contribute to the broader discourse on sustainable management practices, particularly within industries crucial for decarbonization efforts.

Based on the presented objectives the research design elaborated below provides a clear understanding of the approach undertaken. The research methodology involves conducting a bibliometric analysis to examine the academic landscape surrounding sustainability in the automotive sector.

2. Research Design Including Method and Materials

2.1. Bibliometric Analysis as A Method to Presenting the Current State of Scientific Research, Evolution and Management of Sustainability in the Automotive Sector

A structured frame as shown in the below Figure 1 enables to comprehend the evolving landscape of sustainability research the current state of scientific research, evolution and management of sustainability in the automotive sector is analyzed. By using the bibliometric data and coupling it with advanced visualization tools like the software tool VOSviewer, the trends, influences, and interconnections within this multidisciplinary field are examined. Moreover, the creation of maps depicting co-authorship, co-citation, and co-occurrence relationships enables a deeper understanding of the intellectual structure and thematic evolution of the topic "sustainability". This study has been executed in the timeframe of July to August 2023.

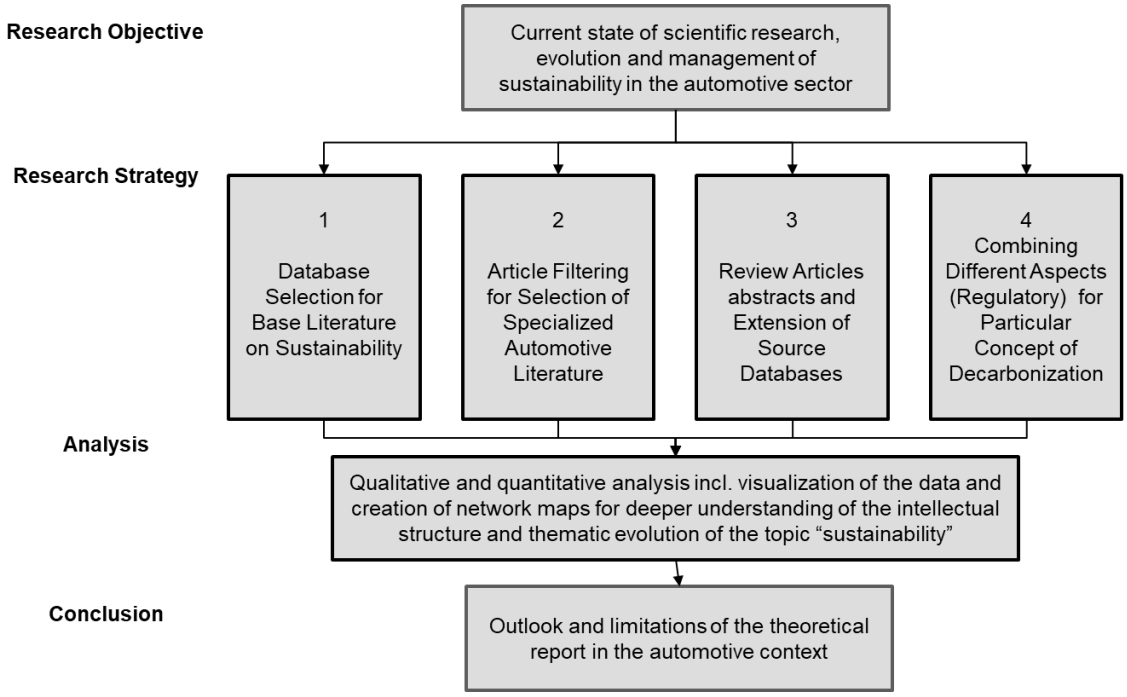

Figure 1. Research Design

1. Given the interdisciplinary content that encompasses environmental science, economics, business, social sciences, and more - the Web of Science's multidisciplinary coverage was found most suitable for the bibliometric analysis to map out the general development of the topic "Sustainability" and provide raw articles. Further recognized **databases** such as Scopus and Google Scholar provide high-quality raw articles, which, in turn, comprehends selecting keywords, searching for articles, and verifying the adherence of keywords to the researched topic.

2. **Filtering** the raw articles database pertaining to determine the scientific recognition of articles, author identification, citation and regional distribution of the topic based on the bibliometric analysis. The database Web of Science retrievals are filtered by the Web of Science related classification *Management, Business* and *Economics*. In addition to Web of Science, the databases Scopus and Google Scholar are used. This do not provide such a classification therefore following keywords "sustainability", "automotive", "mobility", "decarbonization" are chosen and used to search for relevant articles, ensuring adherence to the researched topic. Advanced search features including boolean operators, field tags, and other search parameters to refine the queries and retrieve relevant results efficiently are used in second step to tailor the search with precision for the automotive related publications.

3. **Reviewing** selected of articles concerning the full text of the articles especially by focusing on management of sustainability and placing the research topic in the context of one selected system in this case is the automotive & mobility sector. Selected articles are reviewed, focusing on the full text to understand the management of sustainability within the automotive sector. The research is placed within the context of the automotive and mobility system.

4. **Combining and extending** the research by regulatory and legal aspects to provide a comprehensive view of the evolvement of the sustainability topic. Due to the strong prominence of regulatory citations the research is extended to include regulatory and legal aspects, providing a comprehensive view of the evolution of the sustainability topic. Further

articles concerning this aspect from direct sources are added to gain insights into the context of mobility and automotive.

Analyzing authors keywords and metadata by using VOSviewer software tool. Due course of this step several keyword network maps from the Web of Science source are created to visually represent relationships and patterns among sustainability keywords in the research field. Co-occurrence of keywords in selected documents is used to build a network, with nodes positioned based on their relationships. Keywords that appear together in the same document are considered connected. The strength of the connection between keywords is determined by factors like the frequency of co-occurrence and the context in which they appear. VOSviewer uses algorithms to position nodes in a way that reflects the relationships between keywords. Keywords that are closely related are placed closer to each other. In addition to the Web Of Science database relevant singular sources from Scopus and Google Scholar are added.

Potential limitations of the research are as constraints related to data availability especially in the automotive sector, database coverage due to limitation in database usage, and language bias, are acknowledged to provide context for interpreting the results.

The significance of the research in contributing to the broader discourse on sustainable management practices, particularly within industries crucial for decarbonization efforts, is emphasized.

The high-level structure presented in Figure 2 shows the methodical approach of the bibliometric analysis and the content analysis. In the bibliometric analysis web of science articles related to the keyword sustainability were further filtered by the web of science classification related to Business, Management and Economics and in a last step preselected based on additional keywords as “automotive/ mobility/ decarbonization”. Their abstracts were analyzed focusing on following the guiding questions:

- How did sustainability move from concept to development?
- What are measurements for sustainability in the automotive sector?
- What are decarbonization measures and relevant decarbonization practices in the automotive sector?

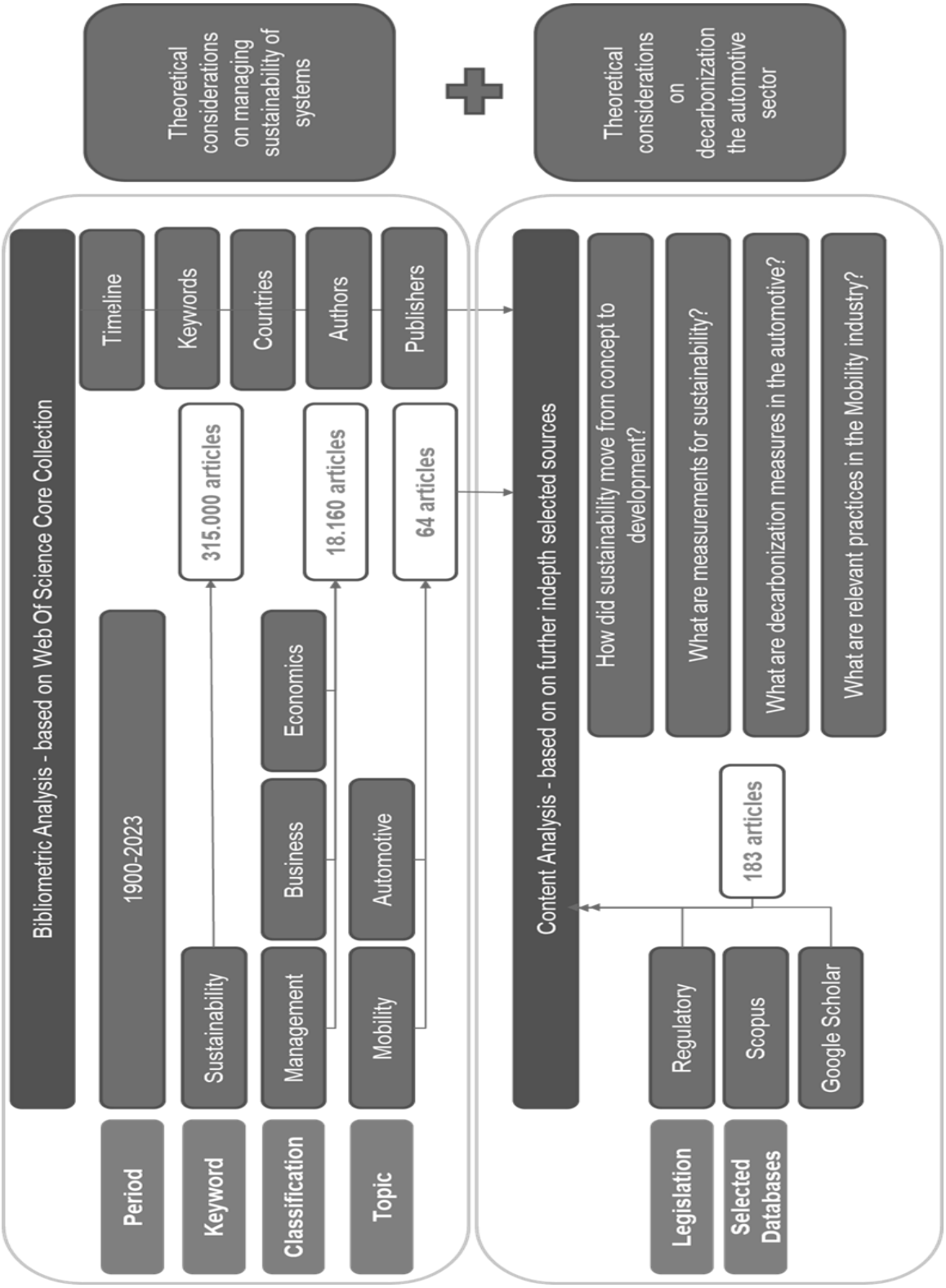

Figure 2. High-level methodical approach
Source: Own illustration as of August 2023

2.2. Materials Used to Identify the Current State of Scientific Research, Evolution and Management of Sustainability in the Automotive Sector

With over 315,000 publications listed between 1900 and 2023 in the database Web of Science (WoS) - which is a widely recognized and comprehensive bibliographic database and serves as an indispensable resource for mapping academic output - sustainability is a core topic to address.

The concept of sustainability has gained unprecedented attention across academic, corporate, and policy circles, reflecting growing concerns about environmental degradation, social inequities, and economic imbalances. Herein we see an ascending trend with over 70% of the publications evolving during the last 5 years and reaching a compound annual growth rate (CAGR) of 27% within 5 years proving the emergency of a critical framework for addressing these issues and ensuring the well-being of present and future generations across the world as shown in below Figure 3.

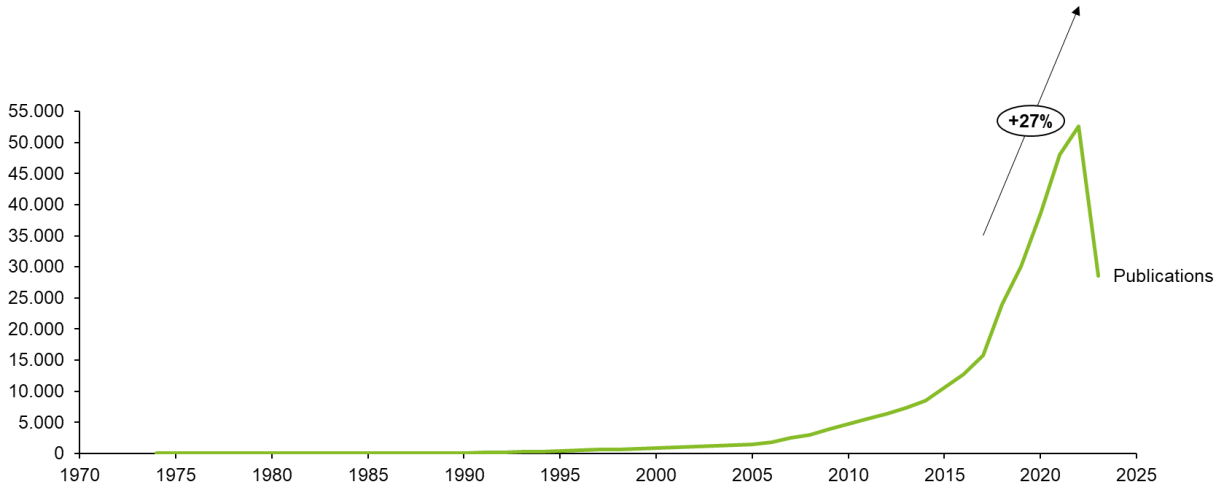

Figure 3. Number of annual "Sustainability" publications paired with 5 year CAGR showing a rising trend
Source: Own illustration based on Web of Science as of August 2023

The WoS classification system provides a standardized way of categorizing articles based on their subject matter, allowing for easier navigation and retrieval of information. A focus on the area management, economics and business will help gain relevant aspects of the studies.

Review of the publication topics and domains based on the predefined classifications clearly focus on environmental, engineering and technology. In effect this means that first attempts to develop the topic have been made at an engineering level providing proof of concepts and ideas on what technologies can drive sustainability. Now businesses need to translate these concepts into long-term strategies.

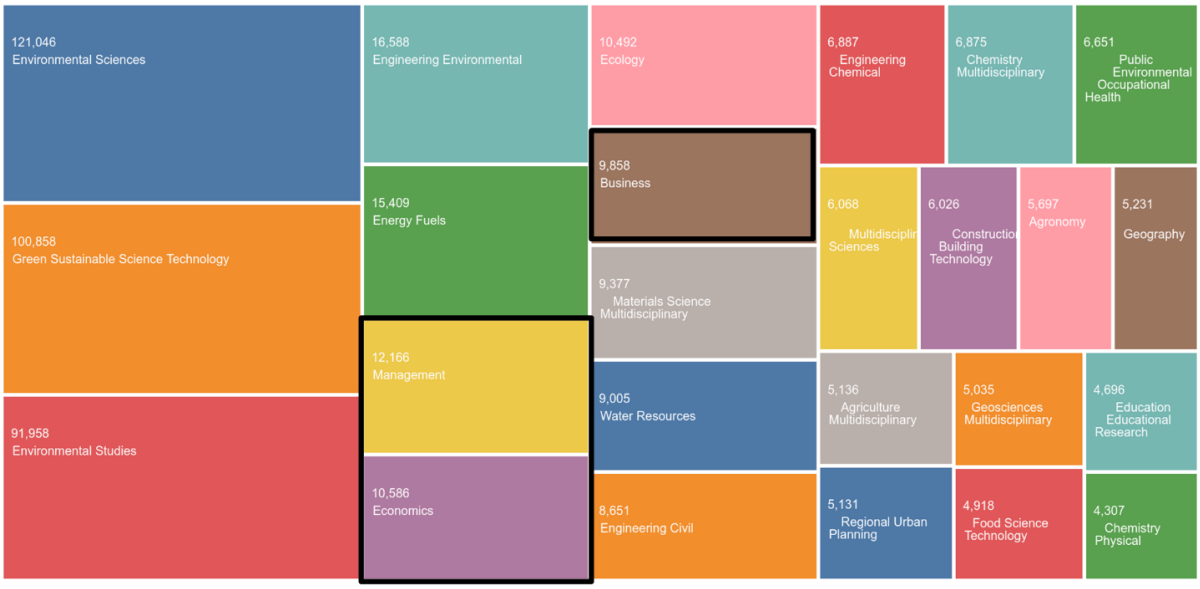

Figure 4: Distribution of WoS publications based on core WoS classification areas
Source: Illustration as in WoS as of August 2023

The above listed source selection approach led to following papers which were used for an in depth content review of the selected articles framing automotive decarbonization. Articles were clustered by areas which appear to be relevant to be tackled further on:

Table 1.
Selected content review based on Scopus research on automotive decarbonization

Authors	**Article Topic**	**Area**
Zhang, C.; Zhao, X. Sacchi, R.; You, F.	Trade-off between critical metal requirement and transportation decarbonization in automotive electrification[1]	Materiality & Ressorce Scarcity
Poschmann, J. ; Bach, V.; Finkbeiner, M.	Deriving decarbonization targets and pathways – A case study for the automotive industry[2]	Political Target Setting
Martins, H. ;Henriques, C.O.; Figueira, J.R.; Silva, C.S.; Costa, A.S.	Assessing policy interventions to stimulate the transition of electric vehicle technology in the European Union[3]	Political Target Setting
Guffarth, D.; Lang, L. Pyka, A.:	Unveiling strategies in recent automotive history. Using patent citations for ambidexterity evidence[4]	Decarbonization approaches
Reolfi, R.L.R. ;Fuchs, E.R.H.; Karplus, V.J.	Anticipating the impacts of light-duty vehicle electrification on the U.S. automotive service workforce[5]	Social Impacts of sustainability
Gan, Y. ; Lu, Z. ; Wu, Q.; Ankathi, S.K.; Wang, M.	Cradle-to-grave mercury emissions of light-duty gasoline and electric vehicles in China[6]	Emissions measurement
Mazzei, J.; Rughi, T. Virgillito, M.E.	Knowing brown and inventing green? Incremental and radical innovative activities in the automotive sector[7].	Product Electrification
Fugger, T.; Poligkeit, J.; Herrmann, C.	Integration of coupled sectors decarbonization pathways across the value chain into corporate carbon management processes[8]	Decarbonization apprroaches

[1] (Zhang, Zhao, Sacchi, & You, 2023)
[2] (Poschmann, Bach, & Finkbeiner, 2023)
[3] (H., C.O., J.R., Silva C, & A.S., 2023)
[4] (Guffarth, Lang, & Pyka, 2023)
[5] (Reolfi, Fuchs, & Fuchs, 2023)
[6] (Gan, et al., 2023)
[7] (Mazzei, Rughi, & Virgillito, 2023)

Authors	Article Topic	Area
Gaeta, M C	Green and Sustainable Mobility in Road Transport: How Private Law Can Guarantee the Right Balance between Environmentally Sustainable Development and Digital Transformation[9]	Political Target Setting
Teske, S.,; Bratzel,S., Tellermann, R.,; Stephan, B.,Vargas, M.	Net Zero: The Remaining Global Market Volume for Internal Combustion Engines in Light-Duty Vehicles under a 1.5 °C Carbon Budget Trajectory[10]	
Pražanová, A.; Knap, V.; Stroe, D.-I.	Literature Review, Recycling of Lithium-Ion Batteries from Electric Vehicles, Part II: Environmental and Economic Perspective[11]	Material & Ressource Scarcity
Salek, F.; Abouelkhair, E.; Babaie, M.; Cunliffe, F.;Zare, A.	Assessment of the Powertrain Electrification for a Heavy-Duty Class 8 Truck for Two Different Electric Drives[12]	Product Electrification
Unar, N.A.; Mirjat, N.H.; Aslam, B.; Ansari, M.; Lohana, K.	Modeling and Analysis of Load Growth Expected for Electric Vehicles in Pakistan (2021–2030)[13]	Product Electrification
Wicki, M.,; Brückmann, G.; Bernauer, T.	How to accelerate the uptake of electric cars? Insights from a choice experiment[14]	Product electrification
Petavratzi, E.; Gunn, G.	Decarbonising the automotive sector: a primary raw material perspective on targets and timescales[15]	Decarbonization approaches
Zhao, F.; Liu, X., Zhang, H.; Liu, Z.	Automobile Industry under China's Carbon Peaking and Carbon Neutrality Goals: Challenges, Opportunities, and Coping Strategies[16]	Political target setting
Conway, G.	Life-Cycle Analysis for the Automotive Sector[17]	Decarbonizaion approach
Eslava-Bautista, J., Cottrill, C.D.; Beecroft, M.	Impacts of decarbonization on the automotive after sales sector: A review of evidence[18]	Decarbonizaion approach
Gebler, M.;Cerdas, J.F.; Thiede, S.,; Herrmann, C.	Life cycle assessment of an automotive factory: Identifying challenges for the decarbonization of automotive production – A case study[19]	Decarbonizaion approach
Landis, F.; Rausch, S.; Kosch, M.	Differentiated Carbon Prices and the Economic Cost of Decarbonization[20]	Decarbonizaion approach
Siskos, P.; De Vita, A.; Capros, P.	The role of carbon standards on passenger cars towards the reduction of GHG emissions in EU: A model-based scenario analysis[21]	Political target setting
Nieuwenhuis, P.	The challenge of decarbonizing the car[22]	Decarbonization approach

[8] (Fugger, Poligkeit, & Herrmann, 2023)
[9] (Gaeta, 2023)
[10] (Teske, Bratzel, Tellermann, Stephan, & Vargas, 2022)
[11] (Pražanová, Knap, & Stroe, 2022)
[12] (Salek, Abouelkhair, Babaie, Cunliffe, & Cunliffe, 2022)
[13] (Unar, et al., 2022)
[14] (Wicki, Brückmann, & Bernauer, 2022)
[15] (Petavratzi & Gunn, 2022)
[16] (Zhao, Liu, Zhang, & Liu, 2022)
[17] (Conway, 2022)
[18] (Eslava-Bautista, Cottrill, & Beecroft, 2021)
[19] (Gebler, Cerdas, Thiede, & Herrmann, 2021)
[20] (Landis, Rausch, & Kosch, June, 2018)
[21] (Siskos, De Vita, & Capros, 2014)
[22] (Nieuwenhuis, 2012)

3. Results

3.1. Academic Evolution and Management of Sustainability in the Automotive Sector

Reviewing the development along the last 5 years in the automotive area we see an inline growth of publications and citations. The Hirsch index (H-Index) measures the productivity and citation impact of publications. The above-mentioned automotive sustainability related publications have a H-Index of 26, with an average citation per publication of 14,73, indicating the high impact of the topic in driving research agendas and policy discussions within the automotive industry. Nevertheless, the H-Index and average citation are not representing sole criteria for evaluating the existing research in this field as other factors, such as the nature of the research, the venues in which authors publish, and qualitative assessments of their contributions, also play a significant role in assessing a researcher's overall impact and importance in their field.

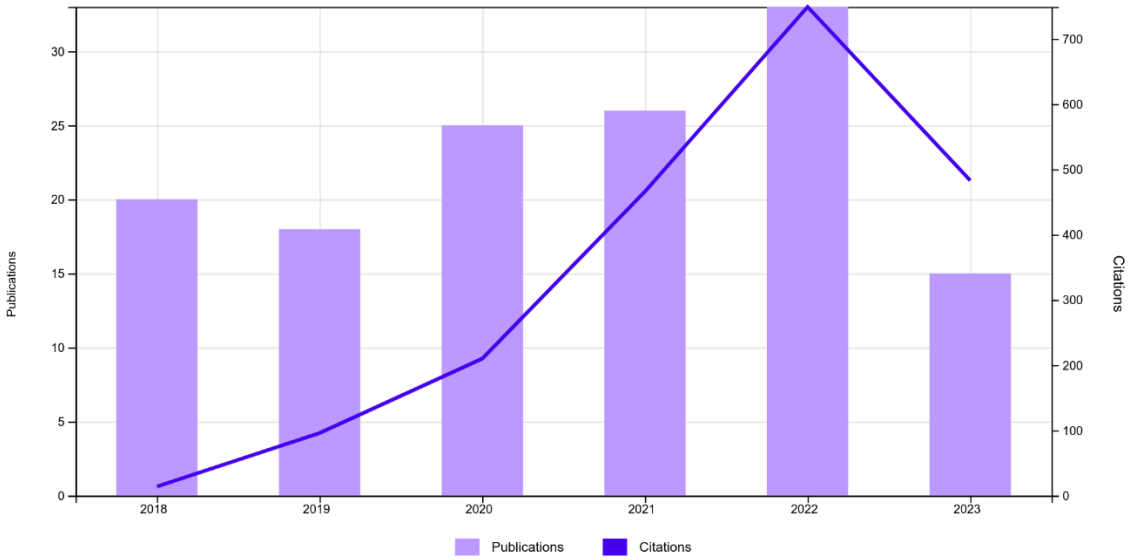

Figure 5. VOSviewer sustainability publications and related citation in the "automotive" area
Source: Own illustration based in the last 8 years

3.2. Geographic Distribution of Sustainability-Related Publications Between 1900-2023

The geographic distribution of sustainability-related publications between 1900 and 2023 showcases a dynamic global engagement with the concept, spanning continents and cultures. Initial academic interest in sustainability emerged predominantly from Western nations, gradually expanding to encompass diverse regions, including Europe, North America, Asia, and more recently, Latin America, Africa, and the Middle East. Now the Unites States, China and England have provided most of the academic input in English language (Figure 5).

Early discussions concerned resource depletion, environmental degradation, and social equity. Over the decades, sustainability research has transitioned from being primarily concentrated in developed nations to increasingly involve contributions from emerging economies and developing countries, reflecting a more inclusive and holistic approach to addressing global challenges. A growing recognition of the interconnectedness of global environmental and social issues was given, while further discussions referred to advances in technology and opportunities given to decarbonize the automotive sector.

Figure 6. Geographic distribution of sustainability-related publications between 1900-2023
Source: Illustration as in WoS as of August 2023

When looking at managing sustainability it becomes obvious that three countries are driving the content generation in this area. Herein the most cited organization are centered around renumated universities.

3.3. Emerging Topic Clusters Around Management of Sustainability in the Automotive Sector Including Challenges and Opportunities

Sustainability core topics are illustrated a network map. Reviewing the illustration of Figure 6 the topics can be clustered in sustainability as core topic (red marked), corporate social responsibility (light blue marked), performance (dark blue marked), framework (purpule marked) and policy (green marked). These five clusters translate sustainability as a core domain into corporate social responsibility for businesses (Sukitsch, Engert, & Baumgartner, 2015), which obviously comes with performance mechanics and initial discussions related on the implementation (Anquetina, Coqueretb, Tavinb, & Welgryn, 2022) (Gan, et al., 2023) (Jasineski, Meredith, & Kirwan, 2016). Moreover, all this not only looking internally at one organization but also checking the outside pressure to make any moves, well-known as policy makers and regulations for example as given in the greenhouse gas emissions protocols (GHG P. I., 2020).

A further keywords analysis has been done providing a quick and intuitive way to identify key terms and concepts within a body of text. The keywords found here can be clustered starting from the authors keywords. Some keywords could potentially belong to multiple clusters based on their context and relationships. The clusters above are just one way to group these keywords. Following potential clusters for authors keywords have been identified:

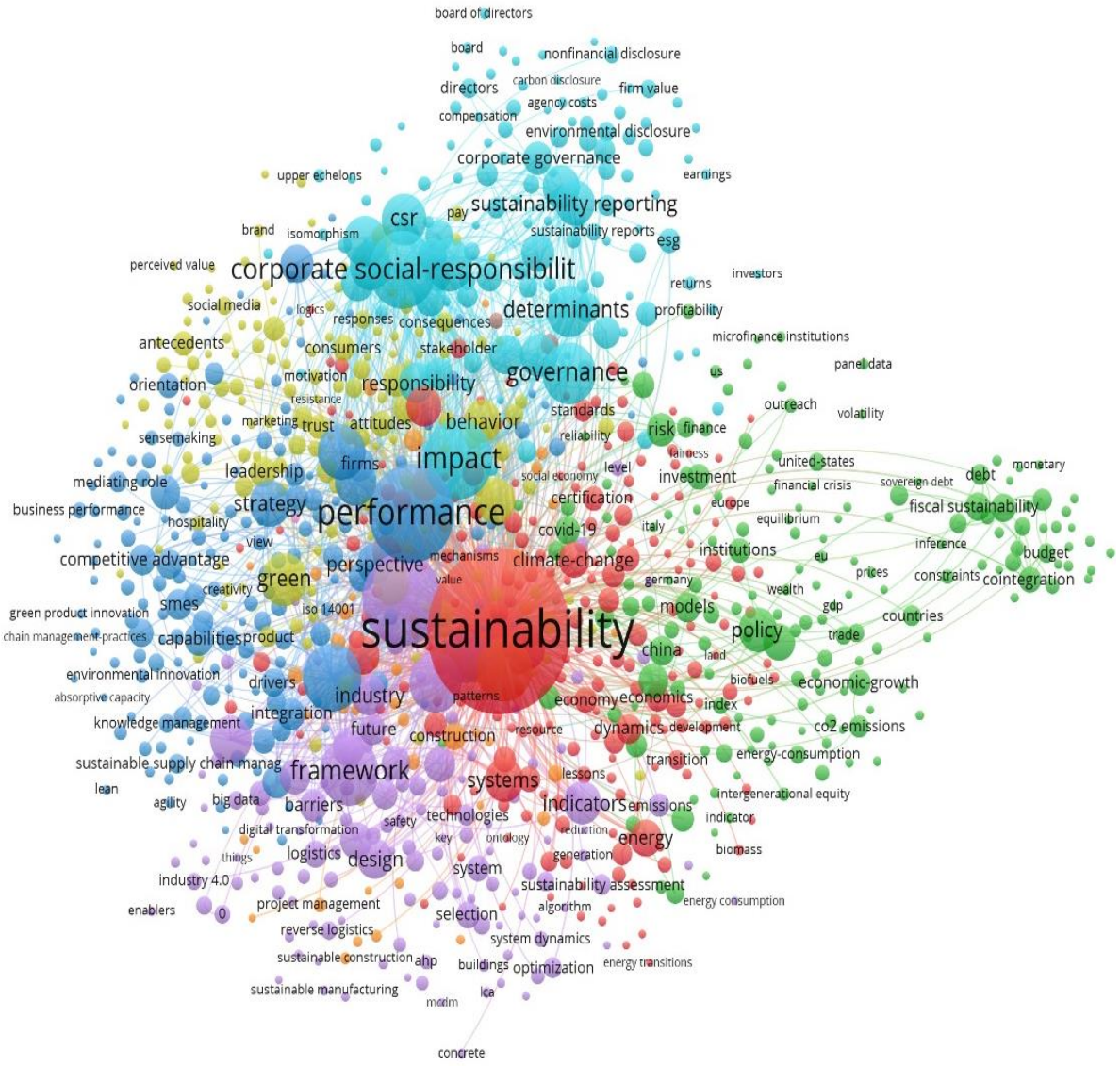

Figure 7. Sustainability network map based on VOSviewer
Source: VOSviewer illustration as of August 2023

- Cluster 1: Automotive industry and technologies e.g. automotive factory, automotive after sales, electrification of vehicles, battery raw materials, automotive supply chain, heavy-duty trucks, battery electric vehicle (BEV), hybrid vehicles, Fuel cell vehicles, electric vehicles (EVs). This cluster shows that the automotive industry is experiencing rapid technological disruption, particularly with the emergence of electric vehicles (EVs), autonomous driving technology, and connected vehicles. Adapting to these technological advancements while maintaining profitability and competitiveness poses a challenge for traditional automakers.
- Cluster 2: Decarbonization and environmental impact e.g. decarbonization, GWP (Global Warming Potential), carbon neutral, carbon footprint, net-zero, environmental impact, emission accounting, CO_2 emissions, climate change, greenhouse gases. This cluster shows that compliance with stringent environmental regulations and emissions standards presents a challenge for automotive manufacturers. Meeting regulatory requirements often requires significant investment in research and development to develop cleaner and more efficient vehicle technologies but demonstrating corporate social responsibility and

ethical conduct is essential for maintaining brand reputation and building trust with stakeholders.

- Cluster 3: Energy efficiency and systems e.g. energy efficiency, energy systems, energy transition, energy management, industrial heat pumps, renewable energies, energy modeling, cogeneration, electric mobility, transport electrification: This cluster shows that automotive supply chains are highly complex and globalized, involving numerous parties. Managing supply chain disruptions, ensuring transparency and sustainability in the supply chain, and mitigating risks related to geopolitical tensions or natural disasters are ongoing challenges. Furthermore, addressing existing infrastructure gaps and ensuring adequate support for electric vehicle deployment is essential for the successful transition to sustainable mobility.
    - Cluster 4: Life cycle assessment and analysis e.g. life cycle, Life Cycle Assessment (LCA), fleet model, fleet modeling, life-cycle analysis, multi-year planning, vehicle cycle, life-cycle assessment, inventory. This shows that decarbonizing the automotive sector not only relates to the manufacturing processes as the consumers play a key role being able to influence most of the emissions caused by the sector. Shifting consumer preferences towards environmentally friendly vehicles, electric vehicles, and shared mobility solutions present challenges for traditional automakers. Meeting the diverse needs and expectations of consumers while staying ahead of market trends requires continuous innovation and agility.

Contrary to the aforementioned challenges, the implementation of sustainability presents numerous opportunities for industry stakeholders, governments, and society at large. Developing sustainable technologies and innovative solutions for vehicle manufacturing and materials can drive competitiveness and market differentiation. Targeted investments in research and development (R&D) for electric vehicles (EVs), fuel-efficient engines, lightweight materials, and renewable energy integration can enable industry leaders to stay ahead of market trends and consumer preferences.

Adopting sustainable supply chain practices, such as responsible sourcing, ethical labor practices, and carbon footprint reduction, can enhance operational efficiency and risk management. Collaboration with suppliers to implement sustainability initiatives and traceability measures can create value and resilience throughout the automotive value chain. Embracing sustainability as a core business strategy and communicating environmental stewardship initiatives can enhance brand reputation, customer loyalty, and stakeholder trust.

Implementing sustainable practices, such as energy efficiency measures, waste reduction initiatives, and recycling programs, can result in cost savings, resource conservation, and operational efficiency improvements. Incorporating circular economy principles, lean manufacturing techniques, and green logistics solutions can optimize resource utilization and minimize environmental impacts across the automotive value chain.

Demonstrating a commitment to sustainability and environmental performance can attract green financing options, investment opportunities, and partnerships with sustainable finance institutions. Accessing green bonds, sustainability-linked loans, and impact investment funds can provide capital for sustainable innovation projects and infrastructure development in the automotive sector.

3.4. Indisputable Role of Regulations and Their Impact on Business Decisions

However, while these opportunities hold significant promise, it's crucial to acknowledge the indispensable role of regulations in driving sustainable practices within the automotive

industry. Regulatory frameworks, such as emissions standards, fuel efficiency requirements, and environmental mandates, play a pivotal role in shaping industry practices and incentivizing companies to adopt sustainable technologies and processes.

Interesting fact is represented in the co-citation references where the role of policy and regulatory frameworks becomes obvious especially related to the greenhouse gas emission protocols and confirming the European driver seat in defining sustainability regulations (Commission, 2023) also being support by key evidence that harmonization and minimum standards are not appropriate. There are several regulatory organizations setting sustainable targets affecting the automotive industry reaching from global to international butr also national departments which need to be taken into consideration. Following list shows some prominent policy and regulatory organizations that play a significant role in driving sustainability efforts:

Table 2.
Role of the organizations driving sustainability discussion in business and their reach

Organization	**Role**	**Reach**
United Nations (UN) & Paris Agreement (United Nations Framework Convention on Climate Change, UNFCCC)	The UN encourages businesses to adopt sustainable and socially responsible policies and practices in alignment with ten principles related to human rights, labor, environment, and anti-corruption. (United Nations Climate Change) Excurse: An international treaty within the UNFCCC framework that aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels, with efforts to limit it to 1.5 degrees Celsius. (United Nations, 2022)	Global
Intergovernmental Panel on Climate Change (IPCC)	Provides scientific assessments on climate change impacts, adaptation, and mitigation. (IPCC, 2023)	International
International Energy Agency (IEA)	Works towards secure, affordable, and sustainable energy for all. (IEA, International Energy Agency (IEA), 2023)	International
European Commission (EC) & European Green Deal (European Union)	The EC provides information about the environment in Europe, supports the development and implementation of environmental policies, and helps assess the effectiveness of these policies. Excurse: A comprehensive policy framework aiming to make Europe the world's first climate-neutral continent by 2050. It includes targets for reducing emissions, increasing energy efficiency, and promoting renewable energy sources. (Commission, 2023)	Regional
Environmental Protection Agencies (EPAs)	The EPA is responsible for enforcing environmental laws and regulations in the United States. It sets standards for air and water quality, hazardous waste management, chemical safety, and more.) (EPA, 2023)	National
National Ministries and Departments	Ministry of Environment, Forest and Climate Change (India) Ministry of Ecology and Environment (China)	National

4. Discussion

Despite the ubiquity of the concept of sustainability, defining the term and interpreting the meaning for different contexts is difficult (Bateh, Heaton, Arbogast, & Broadbent, 2013). The terminological basis is established by the "Global Agenda for Change" by the United Nations General Assembly in 1983 which describes a framework that integrates the "three dimensions of sustainability: economic, environmental and social", which were than presented by Barbier in 1987 (Purvis, Mao, & Robinson, 2018) further represented in the so called Matrjoschka model for supply chain (Krause, 2021). The Triple Bottom Line approach considers three pillars: people, planet, and profit. It emphasizes the need to account for social, environmental,

and economic impacts when making decisions and evaluating performance based on the three P's: people, planet and profit (3P). (Sverdrup & Svensson, 2002)

As a result, in the business field, the consideration of the 3Ps allows companies to broaden their focus from purely economic aspects to environmental and social dimensions, in effect referring to the long-term use of the ecosystem, the intensity of use being such that the available resources and the structure and functions of the ecosystem are not degraded or altered in an unacceptable way.

Contrary to early literature considering the pillars of sustainability as three as distinct perspectives, due course of this research a rather systems-driven approach appears to be more powerful given the global nature of the subject and multidisciplinary context. Designing sustainable systems requires adopting a systemic approach for shaping industrial product and service systems. While numerous business organisations have embraced sustainability objectives as shown by the Science Based Target Inititiative (SBTi), the effective creation of sustainable systems remains complex due to the multifaceted interplay of economic, environmental, and social factors across the entire lifecycle of the system. To stimulate a broader adoption of systems thinking in the automotive context, a design framework needs to be introduced. In effect placing automotive processes in the context of the organization and moving up to the entire ecosystem, which in effect sets the boundaries and limits for sustainability as well as for decarbonization.

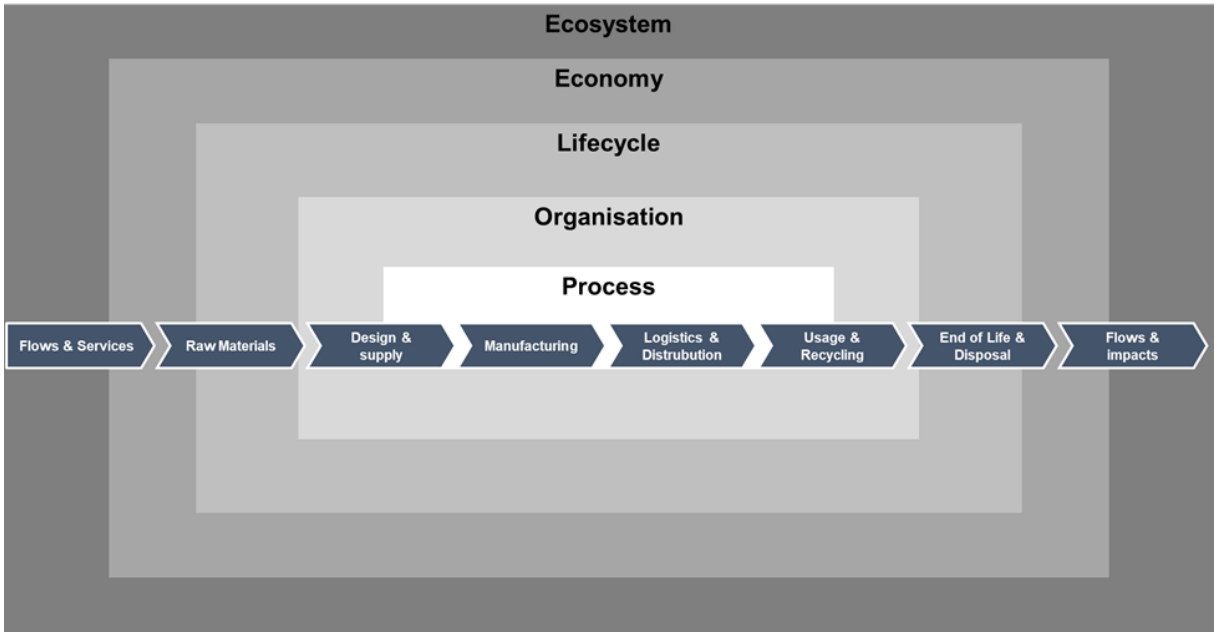

Figure 8. Boundaries of system design adapted to encompass Scope 1,2,3 Emissions
Source: Boundaries of system design adapted based on J. Fiksel

The geographic spread of publications reflects regional variations in environmental concerns, socio-economic contexts, and policy priorities, contributing to a rich tapestry of perspectives on sustainability issues, which are fraught with many difficulties along the entire lifecycle of the automotive value chain (Gebler, Cerdas, Thiede, & Herrmann, 2021) not being able to keep pace with the needs of decision makers and stakeholders (Nijkamp, Environment and regional economics , 2002).

The scientific approach to decarbonization draws on a range of disciplines, including climate science, environmental science, economics, engineering, and policy analysis. It involves interdisciplinary collaboration and the integration of multiple sources of data and evidence to

inform decision-making (Fugger, Poligkeit, & Herrmann, 2023). In effect putting all these factors in practice creates an unmanageable complexity for many actors (Nieuwenhuis, 2012) as decarbonization involves a range of strategies, policies, and technologies. These may include transitioning to renewable energy sources such as solar and wind power, improving energy efficiency in buildings and transportation and implementing carbon pricing and emissions trading schemes e.g., as the different policy instruments for containing the environmental intrusion of transport related to vehicles, fuel and traffic. Therefore, efforts are limited to analyzing the sources of emissions of one single company or product - known as scope 1,2,3 emissions - and focusing on the core value adding activities (Zapf, Martin, Bütler, & Bach, 2021) (Petavratzi & Gunn, 2022), excluding other potential emissions factors as e.g. information technology which becomes more and more relevant in near future.

Limitations include the cost benefit analysis of selected decarbonization strategies (Guffarth, Lang, & Pyka, 2023) or technologies. Even tough signposts, forecast and predictions are broadly available in the market evidence of the overall decarbonization cost and benefits are missing. There is a general understanding across sectors and countries that reaching a “point of no return” will have significant impact on the future of humanity, nevertheless there is a high uncertainty in what the effects really are. Herein there is rather a fear of a negative impact of climate change which could lead to a range of consequences posing significant risks to human societies and ecosystems (United Nations, 2022).

5. Conclusion

The core controversy of sustainability in a business environment is created by the relationship between growth and environment (Eslava-Bautista, Cottrill, & Beecroft, 2021), whereas many argue about conflicting target setting (Van den Bergh & A, 2002) (Heimel & Krams, 2021) (Haessler, 2020). While the costs are significant (McKinsey, 2022), they are also "far outweighed by the benefits" of reducing the impacts of climate change (IEA, Net Zero by 2050 - A Roadmap for the Global Energy Sector, 2021) (Pinner, 2018). Even more as the transport sector emissions have grown faster than almost any other economic sector since the last 50 years – there is a high risk to continue this path if no action is taken (United Nations, 2022).

Remarking the importance of regulations and incentives set which are driving the discussions following conclusions can be drawn:

- There is a dynamic global engagement reflecting diverse contributions across continents and cultures. Global topic developments is driven by the UN- Paris Agreement (GHG P. I., 2020)
- On European level the European commission (EC) & European green deal (European union) are trusted sourced cited often
- National governments which are rather mentioned as single contributors are responsible in the end to translate the targets into executable goals, but currently show a high dispersity in their ambitions and very different development levels.

The link between sustainability and performance becomes visible especially when reviewing the identified clusters. Topics as corporate social responsibility, policy but also decarbonization frameworks set the most important clusters (Poschmann, Bach, & Finkbeiner, 2023). Macro-economic modelling is playing a central role in the analysis of environmental issues (Ierland, 2002) (Conway, 2022) (Teske, Bratzel, Tellermann, Stephan, & Vargas, 2022), well knowing that there is no one single model being able to replicate the reality (Fauchex & Levarlet, 2002).

In essence, the groundbreaking nature of this work not only underscores its paramount importance but also exemplifies its indispensable utility and necessity in translating sustainability concepts within the automotive business sector into actionable and executable strategies on a global scale.

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