SUSTAINABLE MATERIALS IN THE TIRE INDUSTRY: A CROSS-CONTINENTAL COMPARATIVE STUDY OF EUROPE AND ASIAN MARKETS

by

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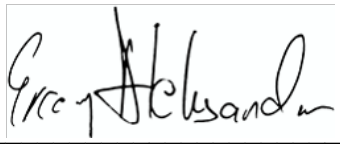
APPROVED BY 

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Admissions Director

Dedication

To my family, loving wife Aarathy and my dear son Adithya, whose steadfast love and support have served as my compass along this journey. This accomplishment would not have been possible without your support and sacrifices. Especially to my dear son Adithya, I know I have taken the quality time I could have spent with you. I thank you in advance and express my love and gratitude for this thesis.

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Finally, I express my gratitude to God Almighty, to whom I devote this thesis and who provided me the strength, inspiration, and confidence to take on this challenging endeavor. I offer this effort in thanksgiving and faith as a humble declaration of His mercy.

ABSTRACT

SUSTAINABLE MATERIALS IN THE TIRE INDUSTRY: A CROSS-CONTINENTAL COMPARATIVE STUDY OF EUROPE AND ASIAN MARKETS

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As the global tire industry confronts the pressing need for sustainability, the researcher conducts a comparative analysis of how sustainable materials are being adopted and implemented in the tire manufacturing sector, specifically focusing on the Asian and European markets. This thesis aims to shed light on disparities, trends, and the driving factors behind the integration of sustainable materials in these major automotive and tire markets.

To start off, the researcher provides an overview of the challenges faced by the tire industry. The researcher emphasizes the tire industry's substantial contributions to resource depletion and carbon emissions, highlighting the urgency of transitioning towards more sustainable manufacturing practices and sustainable material usage. Furthermore, the study explores how both the Asian and European markets are responding to this need.

This research meticulously examines the materials used in tire production, such as alternatives to synthetic polymers, recycled materials, innovative composites, rubber fillers, and other materials like plasticizers, and evaluates how the use of sustainable materials varies across both regions.

A central aspect of this thesis involves a comparative analysis of the economic and technical feasibility of adopting sustainable materials in the tire industry, accounting for the diverse market dynamics, regulations, and consumer preferences in Asia and Europe. The study also investigates the challenges and opportunities that manufacturers encounter as they seek to transition to more sustainable material usage.

To substantiate the comparative findings, the thesis incorporates interviews and surveys of tire and raw material manufacturers and end users from Asian as well as European markets, illustrating successful strategies and innovative approaches. These case studies offer practical insights and potential pathways for manufacturers aiming to align their practices with sustainability goals.

In conclusion, this research underscores the importance of regional variations in the adoption of sustainable materials within the tire industry, recognizing that cultural,

economic, and regulatory factors influence the rate of transformation. The findings of this study emphasize that while there are common goals in the Asian and European tire markets to adopt sustainable materials and practices, unique challenges and opportunities exist in each region. Ultimately, this thesis encourages a collective effort towards more sustainable tire material usage and manufacturing practices, promoting the greener future of the global tire industry.

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INTRODUCTION

1.1 Introduction

The automotive tire manufacturing sector is one of the largest industries globally (IBIS World, 2021). Currently, following the advent of automobiles and tires, it is inconceivable for society to envision a world devoid of the tire and automobile sectors. The consumption of raw materials increases in direct proportion to the growth of the industry. The industrial sector contributes to global warming through the generation of carbon dioxide (CO2), the utilization of groundwater, and the consumption of non-renewable natural resources (Tsai, 2018), (Bridgestone Corporation, 2021). Tire Industries initiated measures to minimize their adverse environmental impact by reducing the quantity of raw materials used in the manufacturing of automotive tires (Imarcgroup, 2024). By 2030, the leading tire producers globally are striving to attain carbon neutrality (Bridgestone Corporation, 2021), (Young, 2020). The approach entails reducing the use of raw materials, decreasing the weight of tires, increasing the utilization of natural and renewable resources, and reducing dependence on petroleum-based resources, all while enhancing quality metrics (Bridgestone Corporation, 2021). Moreover, the sector is actively enhancing its energy efficiency while simultaneously decreasing its reliance on non-renewable energy sources. Manufacturing and mechanical innovations also make a significant contribution to this goal. The Tire industry is currently focusing on sustainable materials as a crucial area that requires further research to achieve the sustainable goals set by WBCSD and TIP.

These research studies offer valuable insights into the usage of sustainable materials in the tire industry and have the capacity to be universally adopted by tire producers worldwide

The principles of 4R (Reduce, Recycle, Re-use, Renewable) and the enhanced version 7R (Reduce, Recycle, Re-use, Renewable, Redesign, Repair, and Recover) are crucial for attaining the goal of Tire production using 100% sustainable materials and minimizing carbon emissions by 2030 (Antony et al., 2021), (Zhongming et al., 2021), (Araujo-Morera et al., 2021). Several innovative tire concepts, such as Michelin's Tweel, Toyo's No-air, Bridgestone's Airless, and Hankook's I-Flex, have been introduced by major tire companies with the aim of achieving sustainability and carbon neutrality by 2030. The most recent tire prototype developed by Nokian Tires is composed of 93% recycled or renewable materials, which has become the standard in the industry (Nokian Tires, 2022). Internationally, leading tire companies are increasingly adopting sustainable practices such as utilizing renewable materials and implementing energy-efficient technologies (Deng et al., 2023). These include incorporating solar power systems within their manufacturing facilities and using sustainable fuel sources like rice husk and wood briquettes in their furnaces.

Fig 01: 7R Circular Economy (CE) Model (Source: Araujo-Morera et al., 2021)

Fig 02: Linear Economy (LE) Model. (Source: Araujo-Morera et al., 2021)

The Linear Economy (LE) (Fig.02) pertains to the management of products beyond their lifecycle, which results in the release of contaminants into the environment. Adopting Circular Economy (CE) principles will help the industry fulfill its obligations towards the Sustainable Development Goals (SDGs). This involves using sustainable, recyclable, and reusable materials in the tire's design and development, as well as managing the tire's end-of-life (ELT) stage effectively (WBCSD, 2021). The Circular Economy (CE) will optimize the durability and enhance the performance attributes of the tire while also minimizing the environmental impact by lowering the amount of waste disposed of in nature (Ali et al., 2024). This is achieved through a circular process that involves recycling, recovering, reusing, repairing, and rebuilding. The percentages of vehicle tire materials are provided in Figure 03. This information is crucial for managing end-of-life tires (ELT) in terms of material and energy recovery.

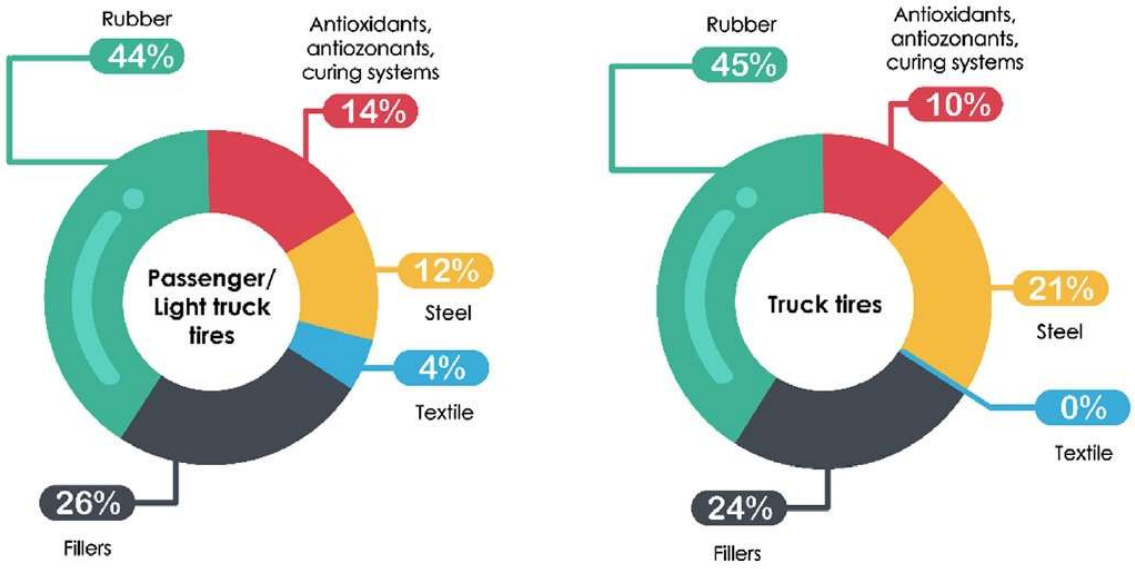


Fig 03: Composition of Vehicle Tire Materials in percentage (%). (Source: Araujo-Morera et al, 2021)

The global tire business is currently confronted with a pressing demand for sustainability. This study examines the adoption and implementation of sustainable materials in the tire manufacturing industry, with a specific focus on the Asian and European markets. The objective of this thesis is to provide insight into the discrepancies, patterns, and underlying variables influencing the adoption of sustainable materials in the automotive and tire industries.

Initially, we present a comprehensive summary of the obstacles encountered by the tire business (Zabaniotou et al., 2014). We underscore the impact of its contributions to resource depletion and carbon emissions, emphasizing the pressing need to shift towards sustainable manufacturing processes. Additionally, we investigate the responses of both the Asian and European markets to this requirement.

This study thoroughly examines the many materials used in tire production, including alternatives to natural rubber, recycled materials, and innovative composites. We conduct a comprehensive analysis of their performance, durability, and environmental footprint, with a specific focus on attributes such as rolling resistance, wet traction, and tread longevity (Tsai, 2018). Furthermore, we evaluate the degree to which these sustainable materials are being employed in both locations.

An essential component of our study focuses on assessing the viability of implementing materials in the tire industry, considering various market dynamics, laws and regulations, and customer preferences in Asia and Europe. The research also examines the challenges and opportunities encountered by manufacturers in their efforts to embrace environmentally sustainable practices.

1.2 Research Problem

The study of sustainable materials in the tire industry is essential to achieve and exceed the objectives established by the tire industry, World Business Council for Sustainable Development (WBCSD), and the Tire Industry Project (TIP). It is crucial to note the expected compound annual growth rate (CAGR) of 3.6% for the Asian tire industry and 3.11% for the European tire sector by 2023 (Imarcgroup, 2024). The objective is to attain carbon neutrality, manufacture tires composed entirely of sustainable materials, and augment. The main approach employed is the 7R Circular Economy (CE) Model, illustrated in Figure 01 (Bridgestone Corporation, 2021), (Araujo-Morera et al., (2021).

This study conducts a thorough investigation of the usage of sustainable materials in tire industry regions globally, with a specific emphasis on the Asia-Pacific and European

regions, in relation to the production and use of automotive tires. An analysis has been conducted on the current and projected growth rate, as well as the current pattern of material utilization and the planned sustainable material usage. This analysis also examines the Sustainable Development Goals set by the World Business Council for Sustainable Development (WBCSD) and the Tire Industry Project (TIP), as well as the long-term sustainable vision of key tire manufacturing companies for the years 2050 and beyond (Thomas and Patil, 2023). The ELT management systems in both the European and Asia-Pacific areas are compared based on the methodology of ELT management, namely in terms of material recovery, energy efficiency, and process efficiency. An extensive examination of the various materials used in different tire segments reveals gaps and opportunities for employing sustainable materials.

Asian countries have inadequate ELT management systems, while European countries already possess well-established ELT management systems and organizations that oversee the management of ELTs (Valentini and Pegoretti, 2022). While the ELT treatment efficiency for material recovery is commendable in India and Asia, the energy recovery aspect still needs improvement when compared to European competitors (Güngör et al., 2021). Furthermore, the tire industry's efforts to achieve independence from non-sustainable energy sources and implement zero water policies are bringing us closer to the sustainable targets set for 2050 and beyond. The tire industry must consistently research and advance sustainable materials in order to meet the goal of producing tires made entirely from 100% sustainable resources.

Implementing a circular economy (CE) approach, which encompasses sustainable product design, efficient material and energy utilization, effective end-of-life tire (ELT) management, and innovative solutions, can bring the tire sector closer to achieving the goal of 100% sustainability in tire production (Lee, Hu and Lim 2020). The Asia-Pacific region necessitates greater research and attention on sustainability compared to the European region due to the relatively weaker institutions and legislation in place (Thapa, 2023). This will enable us to offer environmentally friendly tires and transportation options that are sustainable for both current and future generations, contributing to a cleaner future.

1.3 Purpose of Research

This research seeks to examine the current and projected status of the Asian and European tire markets with regards to their sustainable practices and material usage. While European countries have well-established ELT management organizations and mechanisms in place to supervise ELTs, the Asian area lacks such institutions and systems (Güngör et al., 2021). Despite the efficient material recovery in the Asian and Indian areas, energy recovery in this area has not shown improvement when compared to European counterparts. Furthermore, the tire sector is making progress towards its sustainability goals for 2050 and beyond by implementing zero water policy and reducing its reliance on non-sustainable energy sources. These efforts align with the aims set by organizations such as WBCDS, TIP, and tire manufacturers. In order to achieve its objective of manufacturing tires composed solely of sustainable materials, the tire industry must continue to engage in research and development of such materials.

There exist discrepancies and differences between the Asian and European regions in the implementation of circular economy (CE) principles, specifically in relation to the 7Rs framework (Antony et al., 2021). These inequalities encompass several aspects, such as sustainable product design, material utilization, energy reduction, and end-of-life tire (ELT) management. Novel and unconventional developments have the potential to bring the tire industry significantly closer to achieving the goal of producing tires that are 100% sustainable. The Asia-Pacific region necessitates more extensive research and attention on sustainability compared to the European region due to the relatively weaker systems and legislation in place (Thapa, 2023). The objective of this research is to analyze the discrepancies between the Asian and European areas in order to assist the tire industries in implementing measures that promote sustainable mobility for both current and future generations, thus contributing to a more environmentally friendly future. ELT management organizations and processes are in place to oversee ELTs, the Asian region lacks these institutions and systems. Energy recovery in the Asian region has not yet improved in comparison to European competitors, despite the fact that ELT treatment efficiency in the Asian and Indian regions is good in terms of material recovery. Additionally, the tire industry's zero water policies and independence from non-sustainable energy sources are moving closer to the targets set by WBCDS, TIP and tire manufacturers and taking steps to achieve the sustainable targets of 2050 and beyond (Mouri, 2016). The tire industry needs to keep researching and developing sustainable materials in order to meet its goal of producing tires made entirely of sustainable materials.

1.4 Significance of the Study

The automotive tire manufacturing sector is among the largest industries globally (IBIS World, 2021). This industry is experiencing rapid growth in both volume and value. The study of sustainable materials in the tire industry is a crucial focus that requires special attention in order to meet and exceed the targets set by the tire industry and organizations such as the World Business Council for Sustainable Development (WBCSD) and the Tire Industry Project (TIP) (Thomas and Patil, 2023). These targets include achieving carbon neutrality, producing Tires made entirely from sustainable materials, and increasing the use of sustainable sources of energy (Bridgestone Corporation, 2021), (Araujo-Morera et al., 2021).

A significant number of researchers and industry professionals were already conducting studies and utilizing sustainable materials in the tire sector. Despite the publication of numerous research papers and articles, there is still a dearth of comprehensive analysis and comparison between a major production region in Asia and a major consumer region in Europe. Additionally, the potential utilization of recycled and sustainable materials in the tire industry has not been adequately explored.

The current research aims to analyze, assess, and compare the sustainable utilization of raw materials in the tire industry, as well as the management of end-of-life tires (ELTs) and related policies, organizations, and practices. Additionally, it focuses on studying the sustainability reports of tire companies and intellectual property and innovation in both Asia and Europe.

The present study is notable for its comprehensive analysis of the characteristics of end-of-life tires (ELTs), sustainable practices, and the use of sustainable materials in both Asian and European regions. The utilization of several research instruments and a larger sample size for gathering primary data enhances the credibility of the data and facilitates a thorough comparative analysis, thereby illuminating any highlighting discrepancies. The current research findings can provide vital insights for the tire and allied industries to comprehend the existing circumstances and implement essential measures to address deficiencies in a more sustainable manner.

1.5 Research Questions

The automotive tire market is experiencing rapid growth worldwide, with a projected compound annual growth rate (CAGR) of 4.3% by 2030 (Research, 2022). This study offers a thorough examination of sustainable methods and material usage in the tire industries of both Asian and European regions. There exist discrepancies between the two regions regarding the implementation and utilization of techniques, systems, and materials that promote sustainability. This research study will address the following research questions

Research Question 1: What are the disparities in sustainability initiatives and the adoption of sustainable materials in the tire industry between the Asian and European regions?

Research Question 2: What factors promote and impede the adoption of sustainable materials in these markets?

CHAPTER II:

REVIEW OF LITERATURE

2.1 Introduction

The Tire Industry is one of the fastest growing industries in the World. Considering the good growth of the industry and material usage patterns, it is an interesting and important field of research. The use of sustainable materials in the Tire industry is a significant field of research that requires particular attention to meet and surpass the goals established by the Tire industry and the World Business Council for Sustainable Development (WBCSD). The primary strategy is the 7R Circular Economy (CE) Model (Fig. 01) which aims to make Tires entirely of sustainable materials, use more sustainable energy sources, and be carbon neutral. (Rossi et al., 2020), (Bridgestone Corporation, 2021), (Araujo-Morera et al., 2021).

In the present study, researcher is carefully studying and analyzing the available literature, like sustainability reports from the tire manufacturing majors across the globe, including Bridgestone, Michelin, Hankook, Sumitomo Rubber Industries, Continental, Kumho Tire, Toyo Tires, Yokohama, Pirelli, Vredestein Tire, Goodyear, Maxxix, MRF Tires, CEAT Tires, Apollo Tires, Ralson India Limited, and BKT. The researcher also reviewed the sustainability targets set by the World Business Council for Sustainable Development (WBCSD), Tire Industry Projects (TIP). This chapter provides an overview of the presently available literature that is relevant to the present study.

Additionally, the raw materials used in the tire industry are also reviewed, which are classified as direct and indirect depending on how they are used. Every raw material

used directly in the Tire manufacturing process is referred to as a direct raw material, and every raw material that is not used in the Tire manufacturing process is referred to as an indirect raw material.

2.2 Literature Review Objectives

Sustainability can be defined as 'meeting our own needs without compromising the ability of future generations to meet their own needs' (Kuhlman and Farrington, 2010). The categorization of raw materials in the tire industry for this study can be divided into two distinct categories: sustainable and unsustainable direct and indirect raw materials. The tire and tire business plays a crucial role in facilitating mobility in the current context. A tire is a complex structure composed of various components made from a range of raw materials. These materials include polymers, fillers, reinforcement materials such as natural and synthetic fabrics and steel cords, process aids and plasticizers like process oils and metallic stearates, as well as vulcanizing chemicals and accelerators (Kumar and Nijasure, 1997). Furthermore, several chemicals are employed to optimize the process, boost the safety of the compounds, and preserve and enhance the chemical, physical, and mechanical characteristics of the vulcanised or cured rubber. Synthetic polymers, carbon blacks, and rubber process oils are derived from petroleum and are not renewable.

The World Business Council for Sustainable Development (WBCSD) set the Sustainable Development Goals (SDGs), and research on sustainable materials for the tire industry is essential for achieving these goals. The tire industry presently employs a diverse range of sustainable and recyclable materials. Using eco-friendly materials can lower your carbon footprint. A carbon footprint is the total amount of greenhouse gas emissions, such

as carbon dioxide, that are directly or indirectly caused by an activity or build up over the life of a product (Wiedmann and Minx, 2008). Tire manufacturers worldwide have established a goal to attain carbon neutrality, or a zero-carbon footprint, by the year 2030. Additionally, they aim to produce tires using 50% sustainable raw materials by the same year (Bridgestone Corporation, 2021). With the intention of aligning the tire industry with the Sustainable Development Goals (SDGs), the World Business Council for Sustainable Development (WBCSD) established the Tire Industry Project (TIP) in collaboration with top tire manufacturers worldwide (WBCSD, 2021).

The current study aims to compare the accomplishments and preparedness of the Asia-Pacific and European tire markets, which are the largest regions for tire manufacture and consumption worldwide, in meeting the sustainable goals established by the WBCSD and global tire industry leaders (Fig. 04). Approximately 60% of tire production facilities worldwide are situated on the Asian continents (Satija A, 2021). The key manufacturing nations in the Asia-Pacific region are China, India, Thailand, Taiwan, Vietnam, and Indonesia. The European tire sector is now experiencing a period of expansion. Germany, France, Poland, the UK, Spain, and Italy collectively account for around 60% of the overall sales in the European region. This pertains to the plans for using raw materials and managing End-of-Life Tires (ELT), as well as the policies for obtaining both indirect and direct materials (WBCSD, 2021), (Shulman, 2021).

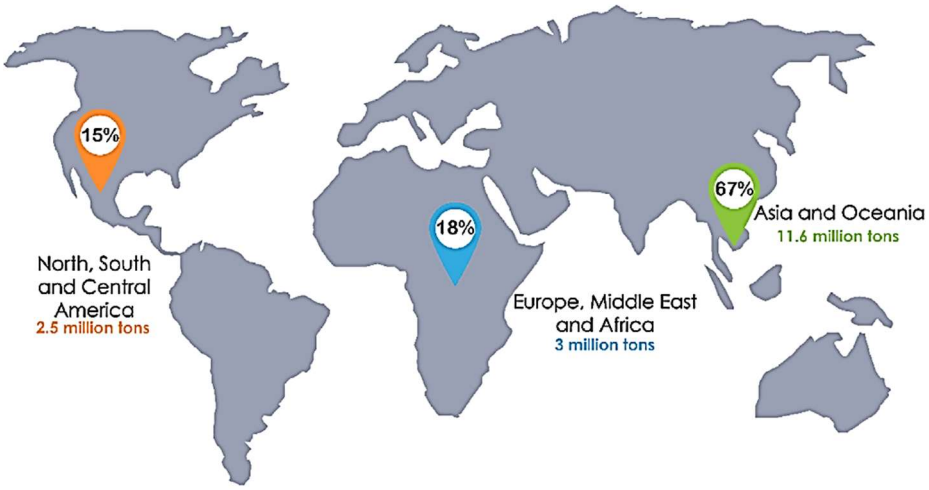


Figure 04: Worldwide Tire Production in percentage (%). (Source: Araujo-Morera et al, 2021)

The tire sector is experiencing steady growth, notwithstanding the challenges posed by the COVID-19 pandemic. The disposal of End-of-Life Tires (ELT) is becoming an increasingly significant concern due to the expanding size and market value of the industry (WBCSD, 2021). Several European countries have established distinct entities and legal frameworks for the management of End-of-Life Tires (ELT), as indicated by Figure 05. In contrast, the Asia-Pacific countries lack specific standards and regulations for ELT (Torretta et al., 2015), (Shulman, 2021). Figure 06 illustrates the global management of End-of-Life Tires (ELT) categorized by country or region. The classification is as follows:

(a) EPR: Extended Producer Responsibility;

(b) Liberal System: Free Market;

(c) Tax System: Government Responsibility; it is funded by taxation.

The tire industry is implementing the 4R and advanced 7R concepts, as well as adopting Circular Economy (CE) practices, in order to meet their sustainability goals (Fig. 01) (Zhongming et al., 2021), (Araujo-Morera et al., 2021). According to sustainability reports from the industry, leading tire companies have established a clear goal to achieve carbon neutrality and produce tires using entirely sustainable raw materials by the year 2050 (Bridgestone Corporation, 2021). The World Business Council for Sustainable Development (WBCSD) and the Tire Industry Project (TIP) have established a set of Sustainable Development Goals (SDGs) specifically for the tire industry. The anticipated release date for the intermediate report of TIP is 2023, while the progress report, scheduled for 2026, will provide an assessment of TIP's successful attainment of its objectives (Zhongming et al., 2020). The TIP project primarily involves tire majors from the European and American areas, with relatively reduced participation from the Asia-Pacific region.

Figure 05: ELT Management Bodies in European Region. (Source: Torretta et al, 2015)

The statistics about the management of end-of-life tires (ELTs), classified by regions and countries, reveal that 28% of the materials are either not being recovered or cannot be traced during the ELT process (Fig 06). The energy recovery efficiency is just 19%, with 51% of the recovered material being used as rubber crumbs for tire production, reclaimed rubbers, and in civil engineering applications such as road and brick construction (Araujo-Morera et al., 2021). The automotive tire sector uses 65% of the world's rubber goods produced, and used tires contribute to 2% of the world's total waste (Dabic-Miletic and Simic, 2023). The energy recovery in the Asia-Pacific area is relatively lower in comparison to that in the European and American regions. In the American region, the energy recovery rate is 48%, whereas in the European region, it is 65%. According to Chinese statistics, 53% of the materials were effectively reclaimed. whereas 47% of the items were either deposited in landfills or not recovered at all (Battista et al., 2020), (Ruwona et al., 2019). The existing data is inadequate to substantiate the feasibility of energy recuperation from ELT in the Chinese region.

Currently, there is a lack of a comprehensive global system for effectively managing end-of-life tires (ELTs), as well as implementing sustainable sourcing and material policies. The aim of this study is to examine and compare the global tire manufacturing and consumption industries, with a specific focus on their approaches and methods pertaining to the sustainability movement. By undertaking this action, the industry will be capable of assessing and addressing the discrepancy within the current sustainable movement, with the aim of achieving the objective of producing tires solely from 100% sustainable materials by the year 2050 (Bridgestone Corporation, 2021).

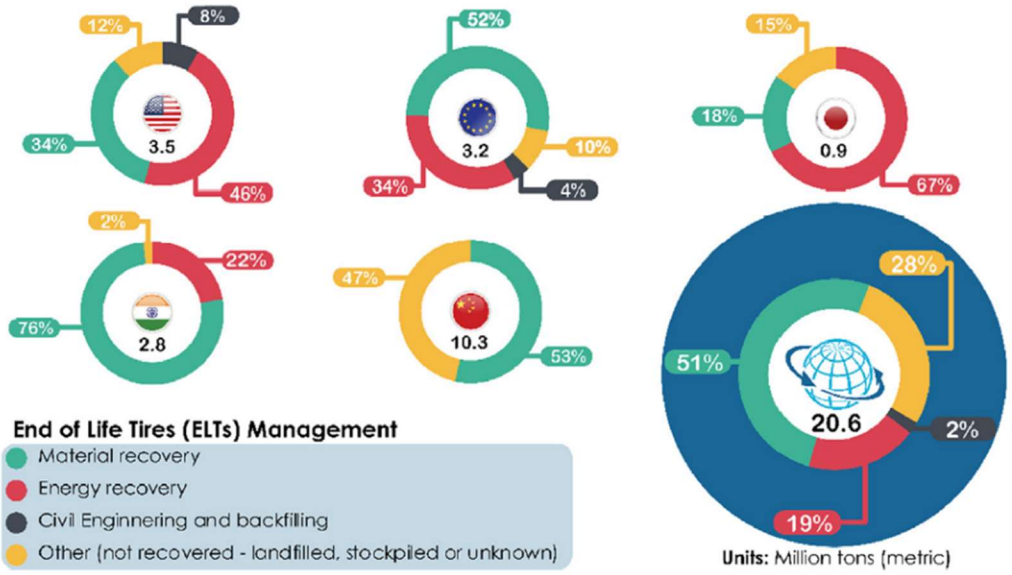


Figure 06: ELT Management by Country/Region. (Source: Araujo-Morera et al, 2021)

A multitude of researchers and industry professionals were already actively involved in the research and implementation of sustainable materials within the tire business. Despite the publication of numerous research papers and articles, as well as the usage of various sustainable and recycled materials in the tire industry, there is still a lack of extensive comparison and analysis between one of the major tire manufacturing regions in Asia and one of the largest tire consumer regions in Europe. The present research is focused on the examination, analysis, and comparison of the usage of sustainable materials in the tire industry, as well as the management, policies, organizations, and practices related to end-of-life tire (ELT) disposal. The objective is to address the disparities in sustainable material usage between Asian and European regions.

2.3 Materials Used in Tire Industry

The tire industry uses a wide range of raw materials to make the rubber compounds and tire components that are the fundamental parts of tires. These components are crucial in defining the finished product's functionality, safety, and environmental impact. Every raw material used directly in the Tire manufacturing process is referred to as a direct raw material, and every raw material that is not directly used in the Tire manufacturing process is referred to as an indirect raw material. As we refine the raw material classification even further, we observe as follows:

2.3.1 Polymers

2.3.1.1 Ribbed Smoked Sheet (RSS)

It is a high-quality type of natural rubber that is obtained from latex harvested from rubber trees. It is characterized by its unique chemical composition, known as cis-1,4-polyisoprene. RSS is subjected to sheeting, ribbing, and smoking processes, which result in a significant improvement of its qualities for diverse applications (Olthuis, 2020). During the production process, the rubber sheets are enhanced with parallel grooves or ribs that improve airflow, resulting in optimal drying when exposed to smoke. Throughout the smoking process, the sheets are hung in smokehouses, where they are subjected to smoke produced by combusting wood or organic materials. This exposure serves to inhibit the growth of microorganisms and imbue the sheets with beneficial characteristics. Due to its low dirt content, resistance, and longevity, RSS is widely used in the manufacturing of tires and several other rubber products. In addition, RSS's environmentally benign

manufacturing process, derived from rubber plants handled in a sustainable manner, underlines its attractiveness as a flexible and sustainable material in the rubber sector.

2.3.1.2 Technically Specified Rubber (TSR)

It is natural rubber (cis-1,4-polyisoprene) that is carefully produced to meet certain quality standards and precise needs. TSR, derived from rubber trees, primarily Hevea Brasiliensis, is subjected to a regulated processing procedure involving coagulation, sheeting, drying, and packaging. This process guarantees consistency in characteristics such as colour, cleanliness, texture, and chemical composition. TSR grades are categorized according to criteria such as dirt content, ash content, volatile matter, and mechanical qualities, which enable their application in precise production processes across several sectors. Based on the country of origin, these are named ISNR, STR, SMR, SVR, and, in general, TSR. TSR, widely used in the automotive, aerospace, electronics, and healthcare industries, is a crucial material for manufacturing tires, conveyor belts, seals, gaskets, hoses, and various other rubber products (Gju, 2020), (Dominic et al., 2020). TSR manufacturing adheres to rigorous quality control methods and promotes sustainability, aligning with global efforts for environmental responsibility. This approach guarantees the consistent performance and durability of rubber-based goods.

2.3.1.3 Synthetic Polyisoprene (IR)

IR (Isoprene Rubber), is a rubber material that is created by combining isoprene monomers through a polymerization process. Synthetic polyisoprene has qualities that resemble those of natural rubber (NR), including exceptional resilience, elasticity, and

tensile strength, rendering it appropriate for a wide range of applications (Cruz-Morales et al., 2023). Synthetic polyisoprene provides a consistent level of quality and purity without the presence of the typical contaminants found in natural rubber latex. Its characteristics make it very suitable for medical applications, including surgical gloves, catheters, and medical tubing, where purity and biocompatibility are of utmost importance. Moreover, synthetic polyisoprene demonstrates remarkable durability against wear, ripping, and weathering, rendering it well-suited for industrial uses such as automotive tires, conveyor belts, seals, gaskets, and vibration isolators. The material's capacity to preserve both flexibility and integrity over a broad spectrum of temperatures boosts its versatility and adaptability to various settings. Synthetic polyisoprene's molecular structure and formulation can also be changed to meet specific needs. This makes it possible to make different grades with better properties.

2.3.1.4 Butyl Rubber

It is also known as Isobutylene Isoprene Rubber (IIR), is a synthetic elastomer that stands out due to its distinctive molecular structure and outstanding qualities. The production of this substance involves the combination of isobutylene and isoprene monomers through copolymerization. This process creates a polymer that is highly saturated, has a high molecular weight, and is very resistant to chemicals. IIR is also very good at blocking gases, which makes it perfect for uses that need to seal tightly and protect against oxygen, moisture, and other environmental factors (Raju et al., 2023). Halogenated versions of butyl rubber are also getting used by the tire industry in tire as well as inner

tube application. In addition, butyl rubber exhibits exceptional resistance to heat, ozone, weathering, and ageing, guaranteeing long-lasting resilience and stability in diverse environments. Due to its low gas permeability and resistance to swelling, it is commonly used for applications such as tyre inner tubes, pharmaceutical stoppers, seals, gaskets, and various automotive, industrial, and consumer uses.

2.3.1.5 Polybutadiene Rubber (PBR)

It is a man-made polymer material produced by combining 1,3-butadiene monomers by polymerization. Polybutadiene rubber stands out for its exceptional capacity to rebound, withstand wear, and maintain flexibility even at low temperatures. As a result, it is a crucial element in a wide range of industrial uses. PBR demonstrates exceptional elasticity and resilience, which imparts long-lasting durability and excellent impact resistance in various applications, including automotive tires, conveyor belts, footwear, and automotive components (Shoda et al., 2020). Its exceptional capacity to endure a diverse array of temperatures and environmental circumstances renders it very appropriate for usage in indoor as well as outdoor applications. Moreover, PBR can be combined with other types of rubber to augment particular characteristics, such as enhancing grip and traction in tire formulations.

2.3.1.6 Styrene Butadiene Rubber (SBR)

Consists of numerous varieties, such as Emulsion SBR (e-SBR) and Solution SBR (s-SBR), each having specific characteristics suitable for diverse uses. The production of e-SBR involves the emulsion polymerization of styrene and butadiene in water, resulting

in a polymer that exhibits remarkable resilience to abrasion and desirable characteristics for enhanced grip in wet conditions. It is frequently employed in tyre production, especially for cars, due to its favorable combination of traction, durability, and cost-effectiveness. However, Solution SBR (s-SBR) is produced using the solution polymerization method, resulting in a polymer that possesses exceptional heat resistance and mechanical capabilities (Dhanorkar et al., 2021). Solution SBR is commonly employed in applications that demand superior resilience and durability, such as high-performance tyre compounds, industrial rubber goods, and adhesives. Although they have distinct characteristics, both forms of SBR make substantial contributions to many industries by offering crucial attributes such as resistance to abrasion, exceptional tensile strength, and long-lasting performance. Due to their adaptability and dependability, SBRs continue to be essential components in the manufacturing of various rubber goods, facilitating progress and innovation across several industries.

2.3.1.7 EPDM Rubber

EPDM rubber is a type of synthetic rubber that is highly resistant to weather, stable at high temperatures, and provides excellent electrical insulation. EPDM is a copolymer composed of ethylene, propylene, and a minor quantity of diene monomers, such as ethylidene norbornene (ENB) or dicyclopentadiene (DCPD), at the chemical level. The inclusion of the diene monomer facilitates the formation of cross-links during the process of vulcanization, resulting in increased flexibility and improved mechanical characteristics (Hough et al., 2020). EPDM's distinctive chemical composition enhances its exceptional

resistance to ozone, UV radiation, and weathering, rendering it extremely ideal for outdoor applications. It retains its flexibility and structural integrity in a broad temperature range, spanning from -50°C to 150°C, with minimal deterioration. EPDM's thermal stability renders it very suitable for automobile seals, gaskets, weatherstripping, and roofing membranes. In addition, EPDM has excellent resistance to water, steam, acids, alkalis, and polar solvents, which makes it highly suitable for a wide range of industrial and construction applications. EPDM is made up of ethylene, propylene, and diene monomers, which give it its unique properties. For example, it is very resistant to weathering, stays stable at high temperatures, and is good at insulating against electricity. The versatility and durability of EPDM make it suitable for a wide range of applications in many sectors, like the tire industry.

2.3.1.8 Reclaimed Rubber

It is an environmentally friendly substitute for virgin rubber and is widely used in the tire industry, making notable contributions to both environmental sustainability and financial efficiency. Reclaimed rubber is manufactured by subjecting discarded rubber, such as old tires, to various procedures like cutting, crushing, separation of non-rubber materials, devulcanization, sieving, and sheeting out in order to transform it into a usable material in tires and other rubber compounding (Fazli and Rodrigue, 2020). The recycled rubber maintains numerous desirable characteristics of virgin rubber, such as elasticity, robustness, and durability.

Reclaimed rubber has several uses within the tire industry. Virgin rubber is frequently combined with it in tire formulations to save production costs without compromising performance requirements. Integrating recovered rubber can boost the processability of tire compounds and maintain or enhance certain attributes, such as rolling resistance, traction, and wear resistance. Moreover, the use of recycled rubber aids in mitigating the environmental consequences linked to tire production by diverting used rubber from landfills and minimizing the need for new rubber materials.

Reclaimed rubber is especially advantageous in manufacturing non-tread parts of tires, such as sidewalls, inner liners, and carcass compounds. These components have lower performance requirements compared to the tread compound. Tire producers can obtain cost reductions without sacrificing quality or safety by incorporating reused rubber in these components.

Moreover, making use of recycled rubber is in accordance with sustainability objectives and legislative mandates in numerous areas, rendering it a compelling choice for tire producers aiming to lower their carbon emissions and mitigate waste generation (Ghorai et al., 2018). Reclaimed rubber is highly beneficial in the tire sector as it provides a sustainable approach to cutting expenses, improving processability, and encouraging environmental responsibility.

2.3.1.9 Crumb Rubber

It is a rubber substance made from the grinding of used tires into tiny grains or particles based on the granule size requirements. Crumb rubber has versatile applications

in automotive tire and tube compositions, contributing to enhanced environmental sustainability and product performance. Also, the use of crumb rubber can maintain or enhance particular characteristics like traction, rolling resistance, and wear resistance (Lapkovskis et al., 2020). Based on the requirements, various mesh sizes of crumb, starting from 40 to 140, are available on the market. In a nutshell, crumb rubber is an extremely valuable recycled material in the tire industry because of its beneficial effects on sustainability, performance, and cost-efficiency.

2.3.2 Rubber Chemicals

Rubber Chemicals can be categorized into two main types: master batch and final batch chemicals. Master batch chemicals are used in the process of mixing master batches. The mixing process can be either single-stage or multi-stage, depending on the specific product and process requirements. Chemicals such as antioxidants, antiozonants, and process aids are used in the process of rubber compounding (Rodgers, 2015). Final Batch Chemicals refer to the specific chemicals used in the process of vulcanizing rubber, which enhance its chemical, physical, and mechanical properties. Sulfur, accelerators, and retarders play a significant role in this area (Kumar and Nijasure, 1997).

Antioxidants and antiozonants are important additives in the process of tire rubber compounding. They cooperate to shield tires from ozone and oxygen-related damage (Thornley, 1964). These materials are essential for improving the durability, lifespan, and efficiency of tires, ensuring their safety and dependability while driving. Antioxidants are substances added to inhibit oxidation processes, which can cause the deterioration of rubber

polymers. They function by scavenging free radicals produced during oxidation processes, therefore impeding chain reactions that lead to polymer breakdown (Li and Koenig, 2005). Antioxidants are very effective at preventing deterioration due to the effects of high temperatures and oxygen exposure. They play a crucial role in preserving the flexibility and physical characteristics of tire rubber as time passes.

Antiozonants are substances added to rubber to protect it from deterioration resulting from exposure to ozone. Ozone, an extremely reactive variant of oxygen found in the atmosphere, has the ability to infiltrate rubber substances and induce surface deterioration such as cracking, checking, and other forms of degradation. Antiozonants work by chemically interacting with ozone molecules, resulting in the creation of stable by-products that effectively hinder any additional ozone damage to the rubber surface. Antiozonants prolong the lifespan of tires and preserve their structural integrity by preventing ozone-induced damage. When making tire rubber, phenolic antioxidants like IPPD (N-isopropyl-N'-phenyl-p-phenylenediamine) and 6PPD (N-1,3-dimethylbutyl-N'-phenyl-p-phenylenediamine) are often added to keep it from breaking down when it gets hot during use (Zhou et al., 2023). Amine antioxidants, such as TMQ (polymerized 2,2,4-trimethyl-1,2-dihydroquinoline), are often used as secondary antioxidants to give extra protection against oxidation (Loélia Fohet et al., 2023).

Paraffin wax and microcrystalline wax, both of which possess antiozonant properties, are commonly used to protect tyres from ozone-induced degradation under static conditions. These materials create a defensive layer on the tire's surface, which

hinders the entry of ozone, decreases the likelihood of surface cracking, and keeps the tire from surface cracking due to ozone attack (Rodgers and Waddell, 2005).

2.3.3 Rubber Fillers

2.3.3.1 Carbon Black (CB)

In tire rubber compounds, Carbon Black (CB) is an important reinforcing filler that is vital to the tire business considering its multifaceted contributions. Carbon black is manufactured by the incomplete combustion of hydrocarbons and is a fine, black powder made of carbon particles. Tires benefit from the improvement of several important characteristics through the use of carbon black. The primary reason for the use of carbon black is to give strength to the rubber compounds and increase the reinforcement of the polymer structure (Parkinson, 1941). This will improve the strength and physical properties of the rubber after vulcanizing or curing (Kumar and Nijasure, 1997). In order to help disperse any static charge that may build up while a vehicle is being driven, there are some special-grade carbon blacks that are electrically conductive. Safety-related concerns like spark-induced fires can be avoided by the use of these types of carbon blacks. It also helps in regulating the heat dissipation as well as the wear resistance of the tire. Based on the requirements of the end user, the tire industry is using different types of carbon blacks in order to fulfil the wear resistance or traction requirements of the tire. Carbon black also helps to absorb ultraviolet (UV) radiation to protect the rubber from degradation from prolonged exposure to sunlight during the lifecycle of the tire (Donnet, 2018).

2.3.3.2 Silica

Tire manufacturers have been using silica more frequently throughout the years because it is a crucial part of tire formulations to achieve targets like rolling resistance, wear, and traction requirements and to reduce environmental impact. Mostly used in combination with carbon black as a reinforcing filler, silica improves tire composition (Waddell and Evans, 1996). Tire manufacturers utilize a variety of silica types, each with unique features. The particular requirements of the tire determine the silica type. Silica is one of the sustainable reinforcement fillers used in the tire industry to improve tire performance (van Hoek et al., 2019). This is a non-black reinforcing filler. The advantage of this filler is that it can be used in black as well as colored compounds. Dispersion is one of the drawbacks of this filler. The tire industry is overcoming the dispersion issues through various process aids and the use of silane-coupling agents (Sae-oui, Thepsuwan and Hatthapanit, 2004). Tire industries use rice husk-derived silica because it is natural and sustainable (Dominic et al., 2020).

2.3.3.3 Inorganic Oxides

In the tire industry, inorganic oxides are significant additives that influence a number of tire characteristics and performance elements (Frazer, 2001). Zinc oxide (ZnO), magnesium oxide (MgO), and titanium dioxide (TiO2) are a few of the important inorganic oxides utilized in tire compositions. Each of these oxides has a distinct function that improves the tires' overall performance, longevity, and quality. Zinc oxide (ZnO) functions as an activator during the vulcanization process, encouraging rubber molecule cross-

linking and improving the curing or vulcanization process (J. Kadlcak et al., 2011). In order to accomplish particular performance qualities and for particular purposes, magnesium oxide (MgO), an inorganic chemical, is occasionally used in tire compositions. It is used mostly as an activator in vulcanization or curing and as an acid scavenger since pH is really important in the processing of rubber compounds. It is also used as an aging resistance aid. The major advantage of titanium dioxide is that it is a reinforcing filler that can be used for white and colored tires, where we cannot use carbon black considering its color. Also, it is an excellent ultraviolet (UV) absorber.

2.3.3.4 Inorganic Carbonates

These are another kind of filler used in the tire industry (Frazer, 2001). These are considered non-reinforcing fillers or extenders, as they are not directly giving strength to the vulcanized rubber; rather, these materials are used to fill the voids, increase the volume, and act as a cheapener or low-cost filler. Calcium carbonates ($CaCO_3$) are one of the examples. In addition to this, aluminum silicates (Al_2SiO_5) and China clay ($Al_2O_3(SiO_2)_2(H_2O)_2$) are some of the examples of non-reinforcing fillers that are used by the tire industry (Dannenberg, 1982).

2.3.4 Reinforcing Fabric and Steel materials

A variety of reinforcing textiles are used by the tire industry to improve the performance, strength, and structural integrity of tires. Throughout the manufacturing process, these textiles are thoughtfully blended into various tire components. Typical reinforcing textiles include the following:

2.3.4.1 Nylon Tire Cord Fabric

Nylon is a synthetic fiber with excellent tensile strength, flexibility, and fatigue resistance. Two popular polyamides, or nylon polymers, with different qualities and uses are nylon 6 and nylon 66. Nylon 6 - $(C_6H_{11}NO)$ n, Nylon 6-6 - $(C_{12}H_{22}N_2O_2)$ n. Applications requiring greater heat resistance and mechanical strength are typically better suited for Nylon 66, whereas Nylon 6 is frequently preferred for those where cost and good mechanical qualities are vital (KOVAC and RODGERS, 1994).

2.3.4.2 Cotton Tire Cord Fabric

Cotton tire cords were once widely used, but their use has decreased in favor of synthetic fibers like rayon, polyester, and nylon, regardless of the fact that, compared to certain synthetic materials, cotton is a more environmentally friendly choice because it is a natural, renewable resource. Presently, its usage is still continuing in the bicycle tire industry (Lambillotte, 1989).

2.3.4.3 PET Tire Cord Fabric

The term "PET Tire cord fabric" describes the use of PET (polyethylene terephthalate) fibers as a reinforcing material in Tire structural construction. PET is a synthetic polymer that is frequently used for Tire reinforcement because of its great tensile strength, longevity, and abrasion resistance (Kovac and T.M. Kersker, 1964). PET tire cord fabric is frequently used in the manufacturing of bias and radial tires, strengthening the tire belt's structural integrity and ability to endure a range of driving circumstances. PET is a

useful material for tire reinforcement because of its adaptability and appealing qualities, which meet the demands of the automotive industry for durability, performance, and safety.

2.3.4.4 Aramid Tire Cord Fabrics

The tire industry uses high-performance, specialized fabric materials for reinforcement called aramid ($C_{14}H_{14}N_2O_4$) tire cord fabrics, like those made of Kevlar, which are one of the major fabric materials used in the tire industry for high-performance tires (Grishanov, 2011). DuPont developed aramid fibers under the brand name Kevlar. It is well known for its outstanding tensile strength, low weight, and remarkable abrasion resistance (Iyengar, 1978). Considering their low weight, these are used to reduce rolling resistance, thereby contributing to improved fuel efficiency and overall vehicle performance. Because of this composition, aramid tire cord fabrics, especially those with Kevlar, are the material of choice when strength and low weight are the primary objectives. Aramid is being used in a wide range of tires, ranging from bicycles to aerospace.

2.3.4.5 NLP - Nylon Like Polyester

It is a synthetic polymer blend combining the best qualities of polyester and nylon. This novel material has found use in tire cord fabrics for reinforcing purposes. In order to maximize the benefits of both nylon and polyester fibers, NLP is designed to offer a balance of qualities (Tian, Wang and Wei, 2019).

2.3.4.6 Reinforcing Steel Tire Cords

These materials are made by wet and dry drawing processes (Korunović et al., 2019). This is being used in the carcass structure of the tire as a ply and breaker. The tire's strength and durability can be significantly improved by using steel tire cord reinforcement. Tire cords, particularly those for radial tires, are made of steel wires that are frequently covered in materials such as brass or zinc. This tire cord fabric coated with rubber helps to maintain the structural integrity of the tire. Because of their remarkable tensile strength, stiffness, and resistance to high temperatures, steel tire cords are essential for withstanding the forces applied during driving. Due to their durability, they are especially well-suited to bearing large loads and preserving the tire's shape in a variety of scenarios. Even with the development of synthetic fibers, tire cords with steel reinforcements are still widely used, particularly in situations where the special strength and heat resistance of these materials are crucial for tire performance and safety. Truck bus radial tires and passenger car radials are the segments where tire steel cords are widely used.

2.3.4.7 Bead Wire

The tyre construction includes a metallic component that is in direct contact with the rim. This component is manufactured using a dry drawing method with metal wire. Bead wire is made up of strong steel wires coated in brass or bronze, which prevents improper tire seating on the rim and preserves the tire's stability and integrity while it is in use (Polyakova and Stolyarov, 2021). Ensuring the requisite strength and elasticity to endure the forces experienced during vehicle operation, inflation, and mounting is its principal purpose. Where it creates a strong bond with the rim, bead wire is thoughtfully

placed all the way around the tire's bead area on the inside. Despite advances in tire technology and materials, bead wire remains indispensable in the tire industry, underscoring its vital role in ensuring tire safety, performance, and reliability on the road

2.4 Product Design

The long-term sustainability of products, especially in sectors such as tire production, depends on embracing a comprehensive approach that begins from the design stage and continues throughout the entire lifespan of the product, encompassing end-of-life tire (ELT) deliberations (Nakajima, 2011). Tire manufacturers can mitigate environmental impact, decrease resource consumption, and foster circularity by incorporating sustainability principles into product design, thereby promoting the reuse and recycling of components.

Commencing sustainability activities at the product design phase is essential, as it enables manufacturers to incorporate environmentally friendly characteristics and practices into the fundamental structure of the product. By placing a high value on durability, recyclability, and resource efficiency during the design process, tires can be manufactured to be more resistant and require fewer resources, resulting in a reduced environmental impact throughout their lifecycle. Optimizing tire construction to minimize material usage while upholding performance standards can greatly diminish material consumption and waste generation (Curtiss, 1973).

In addition, incorporating end-of-life considerations into the design phase allows tire manufacturers to come up with inventive methods for reutilizing or repurposing tires after they have reached their primary lifespan (Duque et al., 2010). Re-grooving and

retreading exemplify sustainable design methods that prolong the utility of tires beyond their initial designed lifespan. Re-grooving refers to the process of creating fresh tread grooves on worn tire surfaces, which improves traction and performance. On the other hand, retreading entails adding a new layer of tread to the tire carcass, thereby revitalizing it (Antony et al., 2021). These measures not only prolong the lifespan of tires but also decrease the need for raw materials and alleviate the environmental consequences of tire disposal.

Furthermore, an additional approach to sustainable design in the tire sector is the reduction of tire mass and material utilization while maintaining optimal performance. Utilizing lightweight tire designs can enhance fuel efficiency, reduce emissions, and alleviate the environmental impact linked to tire manufacturing and shipping (Aldhufairi and Olatunbosun, 2017). Manufacturers can align with sustainability goals and contribute to industry-wide efforts to reduce environmental impact by optimizing tire design to use less material without compromising durability attributes.

Laminated tires are an upcycled product from end-of-life tires and embody a pioneering and eco-friendly method of tire production that effectively tackles environmental and economic issues (Kumar et al., 2022). These tires are manufactured from old tires that have reached the end of their life cycle, preventing them from being disposed of in landfills and minimizing waste while also producing a useful new product. The production of laminated tires generally entails the fragmentation and treatment of used tires into smaller rubber pieces, which are subsequently joined with binders and adhesives to generate sheets or layers of material. Subsequently, these layers are subjected to

compression and curing through the application of heat and pressure, resulting in the creation of a robust tire structure suitable for use in forestry and gardening vehicles.

Laminated tires offer a significant advantage by harnessing the natural durability and elasticity of rubber from discarded tires while also incorporating new methods and technology to improve performance and lifespan. Laminated tires reduce the need for new rubber and other primary materials by integrating a second life of rubber into their manufacturing process. This practice helps preserve natural resources and lessens the environmental consequences associated with tires. Moreover, laminated tires provide similar levels of performance and durability as conventional tires, rendering them a feasible and environmentally-friendly substitute for various uses. They are applicable in various types of vehicles, including forestry, agricultural equipment, and off-road vehicles, ensuring dependable grip, stability, and safety

On the whole, laminated tires provide a hopeful resolution to the environmental issues linked to tire disposal and production. Laminated tires contribute to the circular economy and encourage sustainability in the tire business by transforming discarded tires into high-quality, upcycled products. Laminated tires are a viable and environmentally conscious option for both consumers and businesses, contributing to the advancement of a more sustainable future in response to the increasing awareness of environmental concerns.

Ultimately, it is crucial to incorporate sustainability measures starting from the first phase of product design in order to advance environmental accountability and optimize resource utilization within the tire industry. Tire producers can provide durable and high-performing goods that are also ecologically benign and economically sustainable in the

long term by adopting procedures such as re-grooving, retreading, second-life products, and material optimisation. In essence, sustainable design principles lay the foundation for a tire industry that is both circular and sustainable, ensuring that products are developed with careful consideration for their whole lifecycle, from creation to disposal.

2.5 Usage of Sustainable Materials

In recent years, the tire industry has experienced a substantial change, characterized by a prominent transition towards sustainable practices and the incorporation of renewable materials into tire production methods. This proactive strategy seeks to minimize the environmental footprint while advocating for sustainability throughout the business. Tire production now incorporates key sustainable materials that provide specific advantages in terms of environmental responsibility and efficient use of resources.

The following are the major sustainable materials that are being used in the tire industry:

2.5.1 Natural Rubber

Obtained from the latex sap of rubber plants, natural rubber is a fundamental component in the production of environmentally friendly tires. The tire makers benefit from its renewable nature and biodegradability, which contribute to reducing the industry's ecological impact, making it an environmentally conscious choice. Majors in tire manufacturing are leading a number of studies to commercialize the production of natural rubber from Gauyule and Dandelion (van Beilen and Poirier, 2007), (Sproul et al., 2020).

2.5.2 Silica

It is derived from sustainable sources like rice husks or sand and is an essential reinforcing filler used in tire formulations (Chundawat et al., 2022). Silica plays a crucial role in achieving sustainability objectives in the tire business by promoting traction, minimizing rolling resistance, and improving fuel efficiency.

2.5.3 Plant-derived Oils

There are many materials, such as soybean oil, orange peel oil, and castor oil-derived oils, that provide sustainable alternatives to petroleum-based rubber process oils in tire compounds (Xu et al., 2020). These oils function as efficient plasticizers or processing aids, diminishing reliance on fossil fuels and decreasing carbon emissions during the tyre production process (Neha Kanwar Rawat, Volova and Haghi, 2021).

2.5.4 Recycled Rubber

These are obtained from discarded tires or other rubber goods and serve a vital role in the production of environmentally friendly tires (Myhre and MacKillop, 2002). Recycled rubber, whether integrated into tire compositions or used in re-treaded tires, aids in the reduction of landfill waste and the preservation of important resources, thereby adhering to the ideals of a circular economy.

2.5.5 Bio-Resins

Bio-resins, which are made from renewable sources such as plant sugars or starches, are increasingly being used as alternatives to petroleum-based resins in tire compounds. These bio-based resins offer similar performance qualities while also

decreasing environmental harm and reliance on limited resources (Akampumuza et al., 2016).

2.5.6 Renewable Fillers

Tire makers sometimes employ renewable fillers, such as cellulose or bamboo fibers, to strengthen and enhance the performance of tire formulations. These sustainable alternatives possess similar characteristics to conventional filler materials while minimizing their environmental footprint (Nair and Joseph, 2014).

2.5.7 Polyester Tire Cord Fabric (PTCF)

Fabric, which is derived from recycled PET (Polyethylene Terephthalate) bottles, represents a significant stride towards sustainable tire manufacturing. PET bottles, once destined for landfills or incineration, are repurposed through recycling processes into durable polyester fibers, which are then woven into tire cord fabric (Deng et al., 2023). This innovative approach not only diverts plastic waste from the environment but also reduces the industry's reliance on virgin materials, contributing to a circular economy.

The use of recycled PET in tire cord fabric offers several environmental benefits. Firstly, it mitigates the environmental impact associated with the production of virgin polyester fibers, including energy consumption and greenhouse gas emissions. By repurposing PET bottles, the manufacturing process conserves resources and reduces carbon footprints, aligning with sustainability goals. Furthermore, polyester tire cord fabric from recycled PET bottles maintains high performance and durability standards, meeting the rigorous requirements of tire manufacturing. These fabrics exhibit excellent tensile

strength, abrasion resistance, and dimensional stability, ensuring optimal performance and safety in tires.

Beyond environmental and performance benefits, the adoption of polyester tire cord fabric from recycled PET bottles promotes circularity within the tire industry. By integrating recycled materials into tire manufacturing processes, manufacturers close the loop on resource utilization, minimize waste generation, and support a more sustainable production cycle. Polyester tire cord fabric from recycled PET bottles exemplifies the tire industry's commitment to sustainability and innovation. By harnessing recycled materials, manufacturers not only reduce environmental impact but also enhance product performance and contribute to a circular economy. As consumer demand for eco-friendly products grows, the adoption of recycled materials in tire manufacturing represents a critical step towards a more sustainable future.

2.5.8 Sustainable Polybutadiene Rubber (PBR)

It provides an environmentally conscious option for the production of tires. When sustainable PBR is obtained from sustainable sources such as biomass or plant oils, it decreases dependence on fossil fuels and alleviates environmental consequences (Sarkar and Bhowmick, 2017). It has similar performance to conventional PBR while also retaining robustness and abrasion resistance. Tire producers enhance sustainability and bolster the resilience of the supply chain by incorporating renewable feedstocks. Many tire manufacturers are trying to collaborate with raw material manufacturers to industrialize this sustainable PBR to enhance sustainability efforts.

2.5.9 Sustainable Styrene Butadiene Rubber SBR

Using natural waste to manufacture Sustainable Styrene Butadiene Rubber (SBR) presents a potential prospect for environmentally friendly tire manufacturing. The traditional production of SBR is dependent on petrochemical feedstocks, resulting in the emission of carbon and the depletion of resources. However, by using natural waste materials such as agricultural waste or biomass, the tire industry may significantly reduce its environmental impact and promote sustainability. The production of eco-friendly SBR from organic waste begins with the meticulous selection of suitable raw materials, such as agricultural residues like rice husks, corn stalks, or sugarcane bagasse (Berger and Pfeifer, 2024). These agricultural by-products have a substantial quantity, can be replenished, and are capable of natural decomposition, making them very appropriate for sustainable SBR production. Advanced processing techniques like pyrolysis or fermentation convert the organic components of these waste materials into suitable monomers for SBR synthesis.

Using feedstocks derived from organic waste has multiple environmental benefits. Primarily, it reduces reliance on fossil fuels and non-renewable resources, thereby lowering carbon emissions and mitigating environmental impacts. Furthermore, the utilization of agricultural residues helps divert organic waste from landfills, supporting waste reduction and resource preservation. Moreover, sustainable styrene-butadiene rubber (SBR) obtained from natural waste demonstrates comparable performance characteristics to traditional SBR, ensuring excellent performance in tire applications. The bio-based SBR formulations exhibit remarkable tensile strength, resistance to abrasion, and elasticity, thus meeting the stringent requirements of tire manufacturing while minimizing environmental impacts.

Furthermore, the use of sustainable SBR obtained from natural waste aligns with the principles of a circular economy, which seeks to encourage the recovery of waste materials and optimize resource usage. Tire manufacturers improve the sustainability and durability of their supply chain by integrating natural waste-derived materials into the production processes of Styrene Butadiene Rubber (SBR).

In addition, tire businesses have adopted sustainable sourcing strategies that are in line with global sustainability frameworks such as the World Business Council for Sustainable Development (WBCSD), Tire Industry Project (TIP) and Sustainable Development Goals (SDGs) targets (Rogetzer, Silbermayr and Jammernegg, 2017). These rules give the highest importance to sourcing procedures that are responsible, labor standards that are ethical, and environmental stewardship across the tire supply chain. This ensures that there is a clear record of where the tires come from, that there is a sense of responsibility for actions, and that fair trade practices are followed.

Ultimately, the tire industry's use of renewable materials and sustainable sourcing standards demonstrates a dedication to tackling environmental issues and progressing towards a more sustainable future. Tire manufacturers contribute to worldwide efforts to lessen environmental effects and promote sustainable development by using renewable resources and implementing responsible practices. The tire industry's proactive strategy in response to increasing consumer awareness and regulatory pressure, serves as a model for innovation and positive transformation in the manufacturing sector

2.6 Usage of Sustainable Energy

The tire industry is currently experiencing a significant change as it moves towards decreasing its dependence on non-renewable energy sources (Markovska et al., 2009). The driving force behind this transformation is a cooperative effort that seeks to reduce the environmental footprint and advance the principles of sustainability (Kalak, 2023). A primary goal is to reduce overall energy usage throughout the tire manufacturing operations. Tire producers strive to decrease energy consumption while simultaneously maintaining or improving productivity by introducing energy-efficient technologies and practices, such as optimizing production processes and improving equipment efficiency. Many of the new tire plants are primarily powered by renewable energy sources like solar and energy from non-coal and non-petroleum sources, like tidal and hydroelectric generation sources.

Furthermore, there is an increasing focus on the implementation of zero water waste programmes in tire manufacturing facilities. These activities entail implementing state-of-the-art water recycling and treatment technology to reduce water consumption and eradicate the release of wastewater. The tire industry wants to conserve water resources and minimize environmental contamination by converting current manufacturing facilities into zero water wastage operations.

Many of the new tire factories are coming up with zero water emission plants (Singh, Ramakrishna and Gupta, 2017). Implementing zero water waste methods not only supports sustainable water management but also connects with wider sustainability objectives. Tire makers contribute to the preservation of freshwater resources, maintenance

of groundwater levels, and promotion of ecological balance by lowering water usage and minimizing wastewater output.

Similarly, the tire industry is utilizing mechanical advancements and technological breakthroughs to optimize energy efficiency during the manufacturing process. The utilization of energy-efficient machinery and automated systems significantly contributes to the reduction of energy consumption and environmental impact.

The tire industry's collaborative endeavors to decrease reliance on energy, decrease energy usage, and adopt water conservation measures are crucial measures in attaining sustainable energy consumption and environmental responsibility

2.7 End of Life Tire (ELT) Management

The global management of End-of-Life Tires (ELT) is a significant issue, and many approaches are used to tackle this problem. The key ELT management systems include Extended Producer Responsibility (EPR), Liberal System, or Free Market Approach, and the Tax System. (WBCSD, 2018), (Battista et al., 2021).

The Extended Producer Responsibility (EPR) concept assigns the obligation to tire manufacturers to handle the disposal and recycling of ELTs, motivating them to embrace ecologically sustainable methods. On the other hand, the Liberal system permits a free-market approach, wherein ELT management is determined by market forces and human choice. Furthermore, the Tax System entails the government's obligation to finance ELT management activities through the collection of taxes.

ELTs can yield a variety of valuable goods, such as rubber crumb, reused rubber, and tire-derived fuel (TDF). The materials that have been recovered can be directly used

in the tire industry as components in tire compounds. Pyrolysis and cryogenic methods are employed to manufacture tyre derived fuels and recovered carbon black (rCB) (Rana Ida Sugatri et al., 2017). Additionally, they can also be indirectly used as furnace and process oils (Pipilkaki et al., 2005). Nevertheless, more research is required to comprehensively comprehend and enhance the utilization of tire derived fuel (TDF) in tire compounding procedures.

Tire re-grooving is a widely used method to prolong the lifespan and enhance the performance of tyres, especially in commercial and heavy-duty vehicle use (Markovska et al., 2006). Tire retreading is the procedure of creating fresh grooves or treads on the worn-out surface of a tire, which results in the restoration of traction and enhancement of overall grip on the road. The process of re-grooving involves the use of specialized equipment and machines that are specifically designed to accurately cut new grooves in the tire while maintaining the structural integrity of the tire carcass.

Re-grooving tires allows vehicle owners to optimize the use of their tire resources, decreasing the need for tire replacements and minimizing operational expenses. This method is particularly advantageous in industries where tire degradation is expedited as a result of substantial loads, excessive velocities, or severe working circumstances. In addition, re-grooving enhances sustainability by extending the lifespan of tires and minimizing the amount of tire debris disposed of in landfills or recycling centers.

Nevertheless, it is crucial to acknowledge that re-grooving is not appropriate for every tire type or condition. In order to be eligible for re-grooving, tires must satisfy specific requirements, such as having an adequate amount of remaining tread depth and

being free from any structural damage. In order to ensure safety and the best results, only qualified professionals should perform the re-grooving task using the appropriate equipment. The process of re-grooving tires provides a cost-efficient and eco-friendly method to prolong tire lifespan and improve overall performance. Through meticulous evaluation of tire condition and the use of appropriate methodologies, drivers can optimize the value of their tires while reducing their ecological footprint.

Successful ELT management necessitates the adoption of a range of models and strategies, as well as the use of recycled resources in different contexts. Ongoing research and optimisation endeavors are crucial for maximizing the advantages of ELT recycling and promoting a more sustainable tire industry

2.8 Innovation and Indirect Material Usage

The tire business is currently experiencing a surge of unconventional technologies that are fundamentally transforming the conventional notion of tires. Organizations are developing innovative technologies with the goal of improving longevity, prolonging the lifespan of products, and minimizing the ecological footprint. Notable examples of these developments are the Michelin Tweel, Hankook's I-flex, Toyo's No Air, and Bridgestone's airless tires. (Bras et al., 2011).

These groundbreaking tire designs defy traditional ideas by using new materials, cutting-edge production techniques, and unconventional structures. The Michelin Tweel is a tire that replaces conventional pneumatic tires by using a distinctive combination of flexible spokes and a solid outer tread. This design provides enhanced resistance to punctures and eliminates the requirement for maintaining air pressure. Similarly, the I-flex

tire by Hankook incorporates a pliable sidewall that adapts to varying road conditions, resulting in improved comfort and performance.

The tire business seeks to reduce environmental impact and maximize resource utilization by adopting these unconventional solutions. These technological developments result in a decreased carbon footprint and material use by enhancing the durability and longevity of tires. Furthermore, the implementation of cutting-edge tire designs enhances safety, comfort, and performance for drivers, while also facilitating the transition towards a more environmentally friendly future.

Ultimately, the automotive tire industry's endeavor to develop out of the box inventions represents a significant change towards both environmental consciousness and progress in technology. Companies endeavor to build products that provide exceptional performance, durability, and ecological accountability by re-envisioning tire concepts and pushing the limits of conventional design. These advancements not only provide advantages to consumers but also lead to a more environmentally friendly and efficient transportation system.

Indirect materials refer to materials in tire manufacturing processes that are not directly used but instead have supporting functions. For example, the materials for distribution and packaging. Although these materials do not directly affect the tire's composition, they play a vital role in safeguarding and showcasing the product.

Packaging materials are a significant example of indirect materials in the tire business. There is a unique demand for individual tire packing with a shiny plastic coating in certain markets, particularly in certain Asian nations. Nevertheless, the use of non-

sustainable packaging materials raises environmental apprehensions, namely over the accumulation of plastic waste and pollution.

Conversely, numerous European nations are adopting sustainable and environmentally-friendly packaging materials for tires. These materials place a high value on environmental sustainability and aim to minimize their negative influence on the ecosystem. European tire manufacturers are showcasing their dedication to environmental stewardship and appropriate resource management by adopting sustainable packaging solutions.

Indirect materials chosen for tire manufacturing processes have a substantial impact on environmental sustainability. To minimize its environmental impact and contribute to a more sustainable future, the tire business can prioritize the use of eco-friendly materials for both release and packing. In addition, implementing sustainable practices worldwide can encourage the alignment and uniformity of environmentally conscious methods within the tire industry.

2.9 Summary: Research Gap

Despite the increasing focus on sustainability in the tire industry worldwide, there is still a substantial lack of study on the use and implementation of sustainable materials and practices, especially when comparing the Asian and European regions. Although the two regions share many environmental challenges and regulatory demands and differ in many other parameters, variations in economic, cultural, and business environments can impact the adoption and implementation of sustainable methods and materials in the tire manufacturing industry.

Based on the literature review, the current field of research mostly concentrates on sustainable material advancements and methodologies within specific geographical areas, sometimes neglecting comparative evaluations between Asian and European marketplaces. As a result, there is a lack of knowledge regarding the degree to which environmentally friendly materials and practices are included in tire production processes and supply chains in these areas, as well as the variables that promote or impede their use.

Moreover, there is a lack of research that investigates the efficacy and influence of sustainable materials and practices in lowering the environmental impact, improving product performance, and achieving regulatory standards, especially when considering Asian and European regions. Comparative studies play a crucial role in identifying the most effective methods, difficulties, and potential for adopting sustainable materials and practices. This information is then used to make informed judgements regarding policies, industrial strategies, and technical improvements by government bodies, tire manufacturers, and their associations. The findings of comparative study of European and Asian markets can be crucial for many of the raw material manufacturers in formulating long term strategies and technology roadmaps that align with the priorities of the Sustainable Development Goals of WBCSD and tire manufacturers globally.

To fill this research void, it is necessary to conduct thorough comparative studies on the uptake and use of sustainable materials and the incorporation of sustainable practices in the tire industry in both Asian and European countries. Research in this field should investigate the various aspects that impact the choice, adoption, and efficacy of sustainable

materials and practices. These factors include regulatory frameworks, market dynamics, technological capabilities, consumer preferences, and supply chain considerations.

Furthermore, comparative studies should evaluate the environmental, economic, and social consequences of adopting sustainable materials and practices, offering valuable information about the effectiveness and expandability of sustainable practices in geographical regions of Asia and Europe.

There are differences in the efforts towards sustainability and the use of sustainable materials in the tire industry between Asia and Europe, which need additional research. Also, further research is necessary to comprehend the elements that facilitate and hinder the adoption of sustainable materials in these markets. By addressing these research deficiencies, interested parties like tire and raw material manufacturers and government bodies can gain useful knowledge regarding the possibilities and difficulties linked to the implementation of environmentally friendly materials and practices in the tire business. This will enable well-informed decision-making and promote advancement towards a more sustainable future.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

The tire business is encountering a significant environmental challenge as it endeavours to transition to more ecologically sound manufacturing methods and practices. Traditional tire production techniques heavily rely on non-renewable resources and produce considerable quantities of pollutants and trash, contributing to environmental degradation and climate change. To tackle these issues, it is essential to use more sustainable materials and practices throughout the entire tire manufacturing and distribution system. A comparative study on sustainable materials in the tire industry is crucial for understanding the current scenario and taking necessary steps for meeting and surpassing the goals set by the tire industry worldwide, the World Business Council for Sustainable Development (WBCSD), and the Tire Industry Project (TIP).

Nevertheless, although the tire manufacturing sector recognizes the importance of sustainability, the process of attaining this objective is complex and encompasses various facets. The objective of this research is to analyze the current level of adoption of sustainable materials in the tire business, with a particular focus on the divergent approaches taken by the Asian and European markets. This analysis compares the ELT management systems in the European and Asia-Pacific regions based on the technique of ELT management. Specifically, it focuses on material recovery, energy efficiency, and process efficiency. A comprehensive analysis of the many materials used in different tire

segments uncovers shortcomings and possibilities for the exploitation of sustainable materials.

Asian countries lack sufficient ELT management systems, whereas European countries already have established robust ELT management systems and organizations responsible for overseeing ELT management (Valentini and Pegoretti, 2022). Although India and Asia have achieved noteworthy efficiency in material recovery by ELT treatment, their energy recovery component lags below that of their European counterparts (Güngör et al., 2021). In addition, the tire industry's endeavours to attain self-sufficiency in non-renewable energy sources and adopt water conservation measures are propelling towards the sustainable objectives established for 2050. In order to achieve the objective of manufacturing tires exclusively from 100% sustainable resources, the tire industry must continuously conduct research and make progress in the development of sustainable materials.

Adopting a circular economy (CE) strategy, which includes environmentally-friendly product design, optimized consumption of materials and energy, proper management of end-of-life tires (ELT), and creative solutions, can help the tire industry move closer to achieving complete sustainability in tire manufacturing (Lee, Hu and Lim 2020). The Asia-Pacific region requires more extensive research and dedication to sustainability in comparison to the European region, predominantly due to the relatively less robust institutions and legislation in place (Thapa, 2023). Through initiatives such as sustainable design concepts like lightweight design, more sustainable materials and energy usage, proper ELT management, and such other concepts, companies will be able to

manufacture eco-friendly tires and transportation choices that are viable for present and future generations, contributing to a more environmentally clean future.

This present study seeks to answer the research questions in order to offer valuable insights that can guide policymakers, industry stakeholders, and researchers in understanding the present state and future potential of sustainable materials and practices adoption in the tire business. The research problem aims to contribute to the progress of environmentally sustainable practices and materials in the global automotive industry.

3.2 Operationalization of Theoretical Constructs

Research is a process of systematic and thorough investigation of facts, truths, and realities, employing various methods of interpretation, evaluation, and analysis to arrive at a conclusion. The researcher, by using the research onion concept, develops an appropriate research strategy. The diagram in Fig 07 illustrates the factors that influence the selection of data gathering methodologies and analysis procedures (Saunders, Lewis and Thornhill, 2019).

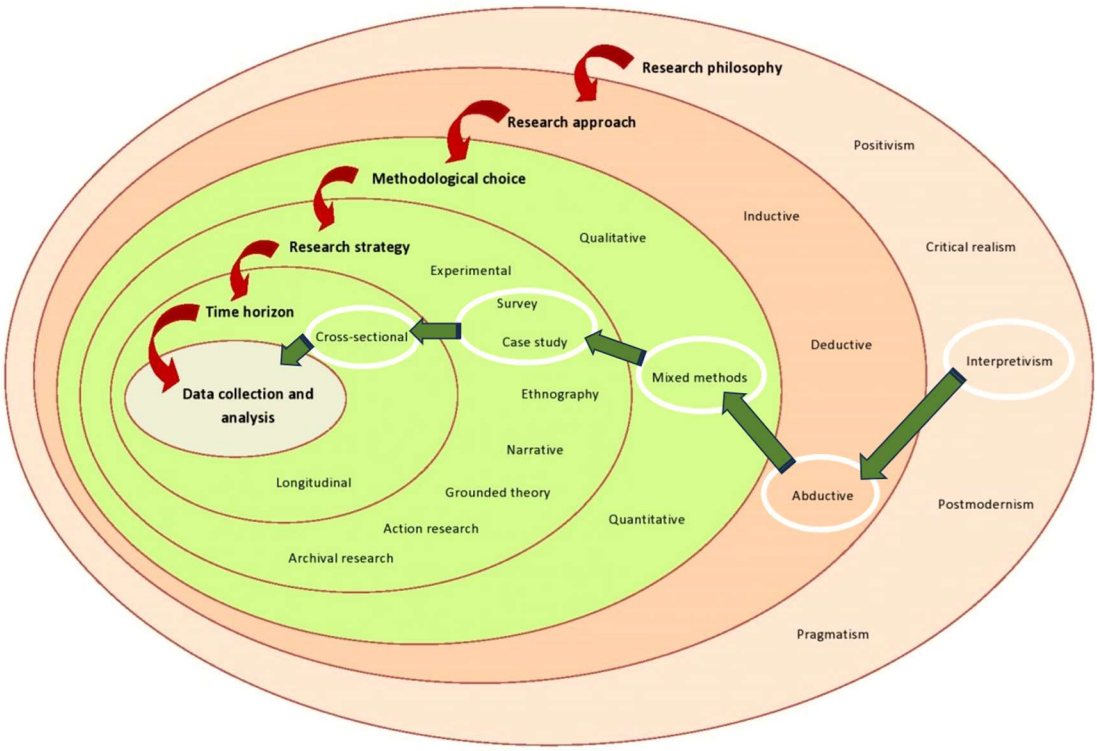


Figure 07: Research Onion (Source: Saunders, Lewis and Thornhill, 2019)

The current study is based on the philosophy of interpretivism. It is a philosophical approach that concentrates on the subjective meanings and interpretations that individuals attribute to their experiences and the social world. The researcher deploys mixed approaches to examine subjective experiences and perspectives, aiming to attain deep understanding of the topic.

The researcher employs the abductive methodology, a highly advantageous way of conducting research, for conducting exploratory studies. In the present study, the researcher employs abductive reasoning to begin the initial assumptions and examination of the empirical facts and then generate probable explanations that closely align with the

observed evidence. The abductive methodology is commonly employed in qualitative research, particularly when phenomena demonstrate intricacy, numerous aspects, and contextual interconnectedness. The researcher is utilizing a flexible and open-minded approach to the investigation, recognising the inherent unpredictability and ambiguity in the study process.

The researcher used mixed methods research, which is a methodology that combines qualitative and quantitative research approaches in a single study. The mixed technique enables the researcher to enhance the understanding of intricate phenomena, validate the findings, and triangulate the conclusions by leveraging the qualities of both methodologies. Mixed methodology involves the collection and analysis of both qualitative and quantitative data and uses diverse techniques such as interviews, surveys, and document analysis of patents and sustainability reports. This versatile approach allows the researcher to investigate research inquiries from various perspectives, encompassing both a wide range and thorough understanding of the topic being studied. The mixed technique is highly advantageous for investigating research problems that possess multiple dimensions, complexities, and facets.

The combining of qualitative and quantitative data is performed at several stages of the research process, encompassing data collection, analysis, and interpretation. The researcher deploys quantitative data to measure trends and patterns, but qualitative data offers context, significance, and explanations for the findings. By employing triangulation,

the researcher corroborates and confirms data derived from many methodologies, thus augmenting the credibility and dependability of their results.

In the current research, the researcher uses research methodologies such as interviews**,** surveys**,** document reviews of patents, and sustainability reports to gather primary data and get profound understanding of diverse occurrences. Interviews entail face-to-face or online meetings with participants from the relevant industries and regions, enabling the researcher to delve deeply into issues and collect comprehensive qualitative data. Surveys, however, employ standardized questionnaires to gather quantitative data from a larger sample, allowing researchers to make generalizations about a wider population.

In this study, the researcher employs a cross-sectional time horizon, which entails a snapshot methodology and the collection of data at a specific moment in time. Cross-sectional studies gather data from a diverse collection of participants at a specific moment, without monitoring changes in variables over a period of time. This approach provides a thorough examination of the linkages between variables at a particular point in time, offering significant insights into the differences among various groups or areas. Cross-sectional studies are valuable in ascertaining the prevalence of an activity, examining correlations between various factors, and generating hypotheses for future research

3.3 Research Purpose and Questions

This research study aims to analyze the present and anticipated conditions of the Asian and European tire industries in terms of their sustainable practices and material

usage. European countries have robust ELT management organizations and established methods to oversee ELTs, whereas the Asian region lacks such institutions and systems (Güngör et al., 2021). Although material recovery in the Asian and Indian regions is efficient, energy recovery in these locations has not demonstrated progress in comparison to its European counterparts. In addition, the tire industry is making advancements towards achieving its sustainability objectives for 2050 and beyond through the adoption of a zero-water policy and decreasing its dependence on non-renewable energy sources. These endeavours are in accordance with the objectives established by organisations such as WBCDS, TIP, and tire manufacturers. To accomplish its goal of producing tires made only from sustainable materials, the tire industry must persist in conducting research and development on those materials.

Discrepancies and variations can be observed between the Asian and European areas when it comes to the use of circular economy (CE) principles, particularly in respect to the 7Rs framework (Antony et al., 2021). These discrepancies cover various elements, including sustainable product design, material application, energy reduction, and end-of-life tire (ELT) management. Innovative and atypical innovations have the capacity to greatly advance the tire industry's progress towards the objective of manufacturing tires that are entirely sustainable. The Asia-Pacific region requires greater research and focus on sustainability in comparison to the European region due to its comparatively less robust systems and regulations in place (Thapa, 2023). The main objective of this research is to examine the disparities between the Asian and European regions with the purpose of aiding tire businesses in adopting strategies that foster sustainable mobility for present and future

generations, thus contributing to a greener future. While ELT management organizations and processes exist to supervise ELTs, the Asian area lacks such institutions and mechanisms. Despite the efficient material recovery in the Asian and Indian regions, energy recovery in these areas has not shown improvement when compared to European counterparts. Furthermore, the tire sector is making progress towards the goals established by WBCDS, TIP, and tire manufacturers in terms of implementing the zero-water policy and reducing reliance on non-sustainable energy sources. These efforts are aimed at achieving the sustainable targets for 2050 and beyond (Mouri, 2016). In order to achieve its objective of manufacturing tires composed solely of sustainable materials, the tire industry must continue to engage in research and development of such materials.

The following research questions were designed to thoroughly investigate the disparities between the tire industries in Asian and European regions in sustainable material usage and practices.

3.3.1 Research Question 1: What are the disparities in sustainability initiatives and the adoption of sustainable materials in the tire industry between the Asian and European regions?

3.3.2 Research Question 2: What factors promote and impede the adoption of sustainable materials in these markets?

3.4 Research Design

To assess the current state of sustainable material usage and practices in the tire industry and to effectively address the research questions, a cross-sectional study on

sustainable materials and practices in the tire industry was designed. Research design refers to the overall approach and structure of a research study (W. Paul Vogt, Gardner and Haeffele, 2012). It provides a detailed outline of the planned research and can be categorized as quantitative, qualitative, or a combination of both.

Exploratory research encompasses the collection and analysis of qualitative data using methods such as interviews, observations, or literature reviews. This approach helps the researchers acquire a greater awareness of the subject that is being studied. This strategy is especially valuable when the subject is new, intricate, or not well comprehended, as it establishes a basis for further targeted research efforts. Exploratory research plays a vital role as an initial step in the research process, establishing the foundation for subsequent, more in-depth and focused questions (Elman, Gerring and Mahoney, 2020).

The interpretivist research philosophy focuses on the subjective understanding and interpretation of social phenomena, prioritizing the exploration of meanings, opinions, and perspectives held by individuals. Interpretivism proposes that the construction and shaping of reality are contingent upon human experiences and interactions (Ryan, 2018). This statement asserts that knowledge is contingent upon the surrounding conditions and influenced by society. As a result, researchers must engage with individuals in their genuine settings in order to gain insight into their own experiences. Interpretivist scholars utilize qualitative research methods, such as interviews, observations, and participant interactions, to reveal other perspectives.

The abductive approach in research uses a form of logical reasoning with the objective of generating probable explanations or hypotheses to justify observable

phenomena. Abductive reasoning, as opposed to deductive and inductive reasoning, relies on formulating competent speculations or creative leaps to suggest the most likely explanation for a set of data (Paul, 1993). The abductive approach is useful in research when current theories or models are inadequate for explaining observable facts or when examining novel or complex phenomena. The abductive approach enables researchers to enhance comprehension and contribute to the accumulation of knowledge in their respective fields by generating speculation grounded in what is known today and further refining it through additional examination.

Mixed methodology research combines qualitative and quantitative research methodologies in a single study to gain a thorough grasp of intricate phenomena. Mixed methodology enables researchers to integrate the advantages of both methodologies, leading to triangulation of findings, validation of results, and enhanced understanding of study topics. This methodology often entails the gathering and examination of both qualitative and quantitative data using techniques such as interviews, surveys, observations, and statistical analysis (Mackey and Bryfonski, 2018). The application of mixed methodology is especially advantageous in tackling complex research inquiries, examining several viewpoints, and producing strong and sophisticated outcomes. It provides researchers with the ability to personalize their research design to suit the unique requirements of their study, resulting in more comprehensive insights that enhance comprehension of the research subject.

The research methodology adopted is a multifaceted technique that integrates surveys, face-to-face interviews, and document analysis to thoroughly examine sustainable practices among tire industries. Surveys provide a comprehensive viewpoint, enabling the gathering of quantifiable data on extensive sustainable efforts and perceptions among various stakeholders. Direct interviews provide a comprehensive examination, enabling an in-depth awareness of the objectives, problems, and innovative approaches implemented by tire companies in their sustainability efforts. Furthermore, examining papers such as patents and sustainability reports offers significant perspectives on concrete measures implemented by organizations, revealing their dedication, accomplishments, and future goals in the field of sustainability. The research strategy aims to unearth comprehensive viewpoints and valuable insights on sustainable practices within tire company operations by combining findings from many sources through triangulation.

The term "cross-sectional time horizon" in research refers to a study design that involves collecting data at a certain moment, creating a fixed perspective of a particular event or situation. Cross-sectional research differs from longitudinal studies in that it collects data from a varied group of participants or subjects at a specific point in time, rather than tracking changes over time. This methodology enables researchers to evaluate the frequency of a condition, behavior, or attribute, as well as investigate connections or disparities across various groups within the population. Cross-sectional studies are useful for capturing a momentary representation of a population's attributes or actions, hence providing insights on the prevalence of conditions, distributions, and correlations. Nevertheless, their capacity to build causal links or infer temporal sequences between

variables is restricted. However, cross-sectional research offers vital insights into the present condition of a community, which can guide additional investigation and intervention efforts.

The current research design is an exploratory study that adopts an interpretivist philosophy. It employs an abductive approach and applies a mixed methodology that combines qualitative and quantitative methods. The research involves conducting surveys and direct interviews with tire and raw material manufacturers and end users. Also, the researcher is reviewing documents such as patents and sustainability reports from tire companies to get an in-depth idea of the research problem and status. The study is conducted within a cross-sectional time horizon.

3.5 Population, Sample and Participant Selection

In the context of research, the term "population" denotes the complete set of individuals, cases, or items that exhibit the specific qualities of interest and constitute the main focus of the study. The population refers to the broader group of people from which a sample is selected, and the research findings are intended to be applied to this entire group (Majid, 2018). The population can fluctuate based on the specific study topic and aims. Precisely defining the population is crucial to guaranteeing the validity and trustworthiness of the research results, as it establishes the extent and relevance of the study.

A sample is a smaller, carefully chosen group from a larger population that is investigated in order to provide insights and draw conclusions about the entire population. The selection is made with the intention of being a fair representation of the entire population, enabling researchers to draw conclusions about the general population

according to the sample's findings. The choice of sampling procedures is dependent upon the research design and aims, with the ultimate goal of achieving a sample that faithfully represents the characteristics of the general population. For instance, in the present tire industry study, the researcher carefully selected a sample of individuals, irrespective of age, from different demographic and geographic areas in order to ensure inclusivity and accuracy in representation.

The present research population and sample were identified and selected from the following category

- Tire Manufacturers from Asian region
- Tire Manufacturers from European region
- Tire Manufacturers from rest of the world
- Raw Material Manufacturers globally
- No Tire Industry (Rubber Manufacturers) globally
- End user Globally

Also, this population and sample were intended to focus more on Asian and European regions.

3.5.1 Participant Selection

The process of selecting participants in research is a crucial element of research design that has a direct influence on the accuracy and consistency of research results. Participant selection in a research project entails the systematic identification and recruitment of individuals, groups, or instances that meet particular criteria and objectives. Participant selection is influenced by various elements, such as the study topic, aims,

demographic characteristics, sampling method, and ethical considerations (Merriam and Tisdell, 2016).

The participant selection for the current study is conducted meticulously, taking into account the tire and its related industries, as well as different demographics, with a primary focus on Europe and Asia. The direct interviews were conducted with experts from the tire, raw material, and related industries. The survey was open to the global population, although the focus was mostly on the European and Asian regions.

3.6 Instrumentation and Data Collection Procedures

Instrumentation in a research encompasses the array of equipment and methodologies employed to gather data and quantify variables within a study. It involves the creation, advancement, and verification of instruments or measurement tools that are employed to collect pertinent information related to the study issue or objectives. Instrumentation is essential in research as it enables the systematic collection and measurement of data, which in turn facilitates the production of reliable and credible research conclusions. Efficient instrumentation guarantees that researchers may precisely evaluate variables, experiment with hypotheses, and make significant contributions to the progress of understanding in their respective discipline.

The present study employs tools like direct interview methods, surveys, and document evaluations, such as patents and sustainability reports, to examine tire companies in the Asian and European areas.

3.6.1 Data Collection Procedures

The researcher identified the research gaps by conducting a literature review. Google Scholar, WIPO Patentscope website, the websites of the tire companies, WBCSD, and the TIP websites were consulted as reliable data sources. Google Forms have been used to develop the survey questionnaire, and direct interviews were conducted via WebEx, MS Teams, and Zoom meetings in addition to in-person interviews.

The survey questions covered a wide range of issues, including attitudes towards environmental responsibility, current sustainable practices, challenges encountered during implementation, perceptions of sustainability initiatives, and future aspirations for sustainability. Thoroughly formulating questions guarantees their clarity, pertinence, and congruence with research goals; this empowers the researcher to identify significant data that effectively tackles critical research questions.

The implementation of Google Forms to generate a survey consisting of 19 meticulously designed questions in order to collect data relevant to research concerns signifies an organized and effective methodology. The researcher derives advantages from deploying Google Forms, including its intuitive interface, adaptable query formats, and streamlined data collection functionalities. The 19 questions chosen indicate an extensive examination of multiple aspects pertaining to sustainable practices in the tire industry. These questions encompass viewpoints from a wide range of stakeholders, including expert individuals employed in tire manufacturing, automotive, raw materials, allied sectors, and end users.

In addition, Google Forms provides various functionalities to streamline the process of survey response collection and dissemination, including email distribution, and social media sharing. Furthermore, the platform offers analysis functionalities and real-time data visualization tools, which empower researchers to effortlessly trace data trends, monitor response rates, and generate reports. In short, the application of Google Forms to generate and distribute an extensive survey concerning sustainable practices in the tire industry exemplifies a systematic and technology-oriented methodology for gathering data. Through taking advantage of the platform's functionalities and active engagement with an international and domestic audience comprising industry experts and stakeholders, the researcher was able to amass substantial, varied, and practical insights that substantially propel the progression of understanding in the domain of sustainable industry practices.

In this data collection procedure, the researcher used data as welll as mothodological triangulation. Triangulation, as employed in research studies, encompasses making use of diverse data sources, methodologies, or viewpoints to substantiate conclusions, strengthen the reliability of research findings, and furnish a more all-encompassing comprehension of the phenomenon subject of study. Triangulation in research entails the process of corroborate information derived from various sources or methodologies in order to bolster the dependability and credibility of the conclusions drawn.

The researchers was able to reduce the limitations and biases associated with single-method or single-source studies by employing triangulation. Through the systematic examination of information from various perspectives, the researcher was able to

authenticate findings, contradictions, and formulate more resilient conclusions. In its entirety, triangulation serves to strengthen the rigorousness and reliability of research findings, thereby augmenting the study's credibility and influence.

3.7 Data Analysis

In the present research, the researcher analysed data from direct interviews, surveys, patent searches, and sustainable reports of tire manufacturers for this study. Firstly, the researcher conducted an analysis of the direct interview data. In order to address the selected research questions, the transcripts were compiled and analysed. The interview comprised a total of seven questions, and the responses were analysed and correlated by query. Qualitative evaluations were used in order to address the research questions.

Subsequently, the researcher conducted an analysis of the patents, which had been categorised by country and then by relevant geography. This was intended to determine which country the patent inventor is a citizen of and to specify the countries in which the patents are applicable. This facilitated the researcher in determining the geographic area that is spearheading the sustainability movement. The present analysis was conducted using quantitative methods, as it involved an analysis of solid numbers.

As a third phase of analysis, in order to address the research questions, the researcher conducted a qualitative analysis of tire companies' sustainability reports. An extensive examination was conducted to contrast the effectiveness and yield of sustainability initiatives geography wise.

The fourth component of the analysis comprised a comprehensive qualitative and quantitative examination of the survey questions. The preliminary bifurcation was carried based on the country of the responsants in the following manner

- European
- Non European
- Asian

Further bifurcations were made according to the occupation of the respondants, as below

- From Tire industries
- From Non Tire industries (All other rubber goods manufacturing)
- Raw Material Manufacturers for Tire and Rubber
- End user of Pneumatic Tire

These data analyses helped the researcher conclude the research questions in quantitative as well as qualitative manner.

3.8 Research Design Limitations

The present research was aimed at identifying the disparities in the tire industry between Asian and European regions. Considering the vast size of the tire and allied industries and the hesitance of participants to respond to the survey as well as direct interview requests, this was a limitation. Many of the European Tire and raw material manufacturers refused to respond to the queries, considering the confidentiality agreement with the companies with which they are working. The same was applicable to China, there was no response to the survey and no interview were conducted. Non-applicability of

Google Forms in China was a reason for this. So we have only analysed the patents related to sustainable materials from China, non-applicability of Google Forms in China was a reason for this. The limitations of the research are the non-generalizability of the responses to few of the research questions.

Furthermore, considering the large number of request views for the survey as well as the direct interview, the response for direct interviews was 21% and response to survey was 2%. Almost 17K views were noticed for the survey request as a consolidation n linkedIn, Whatsapp and direct emails, out of that only 332 were responded to the survey. However, considering 332 responses against the targeted 200 participants for the survey helps to mitigate this issue.

3.9 Conclusion

This chapter presents a thorough examination of the research framework, including numerous crucial elements. To begin with, the research problem is clearly defined, emphasising the particular concern or knowledge deficit that the research seeks to resolve. Following this, an explanation of the theoretical constructs that underlay the research is provided, detailing the conceptual frameworks that guide the methodology and analysis of the study.

The research clearly defines its purpose, providing a clarification of the broader objectives and aims that direct the study. Additionally, the chapter provides a comprehensive analysis of the complexities inherent in the research design, divulging the methodological framework employed and specifying the methods, procedures, and techniques that were deemed suitable for the study. Furthermore, comprehensive

information is provided concerning the population being investigated, which offers valuable perspectives on the larger group to which the results of the study are expected to apply.

The criteria used to select the sample and participants are clearly and comprehensively defined, providing insight into the factors and reasoning that inform the selection procedure. Additionally, the instruments that were employed to collect the data are detailed, delivering valuable perspectives on the measures, tools, or instruments deployed to acquire the pertinent information. The section provides a detailed explanation of the mode of data analysis, detailing the methods and processes employed to efficiently analyse and comprehend the gathered data. Finally, the research's limitations are explicitly acknowledged, taking into account the difficulties and restrictions that were intrinsic to the study's planning, implementation, and analysis.

CHAPTER IV:

RESULTS

This chapter provides an overview of the methodologies that the researcher employed to conduct the study effectively. The researcher deployed a diverse array of research instruments to gather industry opinions and data pertaining to the utilisation of sustainable materials and practices, to which the tire and allied industries generally adhered. A variety of survey instruments, both qualitative and quantitative, were employed to gather data from end users and tire and allied industries worldwide. Through qualitative interviews with senior industry experts from both Asia and Europe, an understanding of the current state of sustainable material utilisation and practice in comparison to the regions of Asia and Europe was obtained.

The interviews were conducted utilising video conferencing internet facilities such as Microsoft Teams, WebEx, Zoom Calls, Google Meet, and calling services. This enabled the researcher, with the interviewee's consent, to record the session and generate a transcript for the purpose of qualitatively comparing the responses of various individuals. The patent search was conducted using the Patent Scope searching facility of World Intellectual Property Organisation. The search involved the use of specific keywords that are connected with sustainable materials and practices in the tire industry. Sustainability reports were gathered from the official websites of the companies, which were targeted for analysis.

4.1 Interview Data Analysis

In light of the enormous magnitude of the tire business, interviews were conducted on a global scale, with a particular emphasis on the areas of Asia and Europe. The purpose of these interviews was to collect qualitative data regarding the usage of sustainable resources and the practices that are deployed by the tire industry and the industries that are related to it. When it came to the potential selection process of interviewee's, the level of knowledge and experience of the people was taken into consideration. As a result of the personnel's hesitation to accept the interview invitation, about sixty one requests were sent out to experts in Asia and Europe. Out of these sixty one requests, fifteen individuals agreed to participate in the interview and provided a positive response. The interview sessions were conducted using various internet-based video conferencing platforms, including Microsoft Teams, WebEx, Zoom Calls, Google Meet, and calling services, in accordance with the interviewees' convenience. The interviews were recorded, and a transcript was produced to do a qualitative comparative analysis between the participants. The graph below illustrates the number of interview requests compared to the acceptance rate on a global scale.

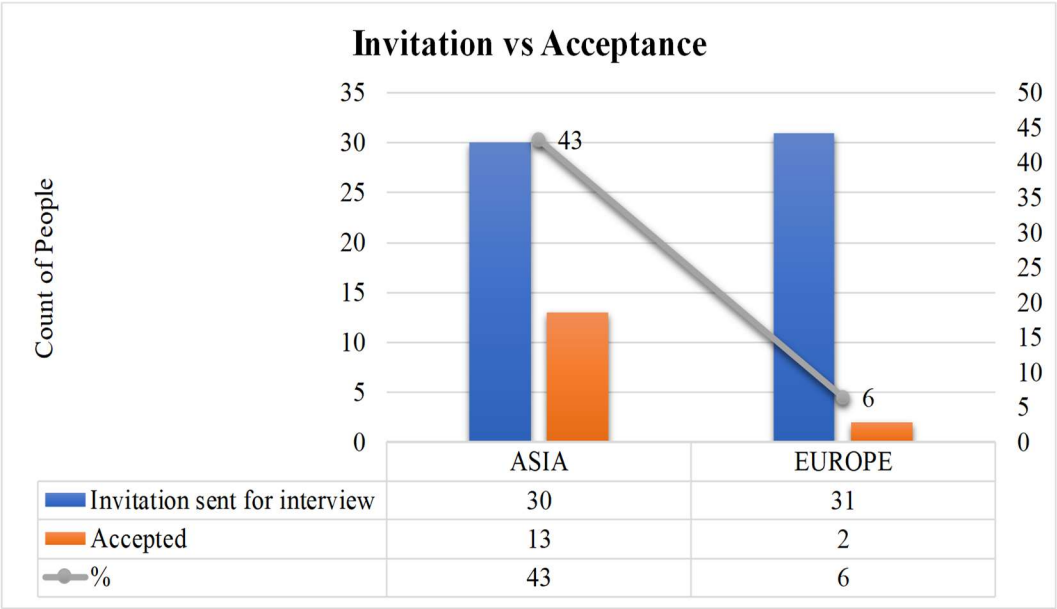


Figure 08: Invitation vs Acceptance - Direct interview

The Asian region had an acceptance level of 43%, while the European region had only 6%. 15 out of 61 interview invitations were accepted, resulting in a 25% acceptance rate. Meaningful interactions were carried out with experts during the interview session to gather qualitative information that would complement the survey data and answer the research objectives. The experienced senior leaders offered significant insights on sustainable materials and methods in the tire and associated industries. There have been many experts who have expressed their belief that the adoption of sustainable materials and practices in the tire industry can be accelerated through the collective collaboration of government authorities, recyclers, and tire manufacturers to meet the targets set by the governments and many tire bodies like TIP.

Seven meticulously designed questions were prepared for the expert interview, focusing on exploring the intricacies of sustainable material usage and practices. The topics that were discussed included regulatory compliance, practices and challenges related to

circular economies, the significance of reducing carbon footprints, the research that is required to maintain the quality of recycled raw materials, potential technological advancements and innovations, measures to enhance transparency of sustainability initiatives, and a comparative view of markets in Asia and Europe.

Question Number	Interview Question
Q1	To what extend do government policies contribute to the promotion of sustainable materials in the tire sector?
Q2	What are the key challenges that tire producers need to overcome in order to incorporate sustainable materials?
Q3	How does the utilization of sustainable materials by the tire industry impact the overall carbon footprint of the transportation sector, and to what extend?
Q4	How do tire producers find a balance between using sustainable materials and complying with safety and performance regulations?
Q5	What are the potential avenues for technological advancements and innovations in the use of sustainable materials within the tire industry?
Q6	What measures can tire manufacturers adopt to enhance transparency in their sustainable practices?
Q7	How do the European and Asian markets compare in terms of the adoption and utilization of sustainable materials in the tire sector?

Table 01. Interview Questions.

A detailed analysis is given below in the order of the questions.

4.1.1 Question 01

To what extend do government policies contribute to the promotion of sustainable materials in the tire sector?

15 personnel responded to this question, and the interview respondents including experts and leadership level executives from tire companies, raw material manufacturers, and non-tire industries indicated that government policies play a crucial role in the adoption of sustainable materials and practices, particularly when comparing Asia and Europe. Government laws, regulations, and guidance are widely acknowledged as crucial factors influencing sustainability efforts, with significant global trends and legislation from the European Union being particularly important. Government policies in Europe have been commended for encouraging innovation, recycling, and sustainable investment, showcasing a proactive approach to environmental stewardship. In other worlds, the European tire market is a mature market in terms of sustainable material usage and other initiatives.

Asian countries such as India have shown a growing commitment to sustainability through initiatives like Extended Producer Responsibility (EPR). Challenges persist in aligning policies with operational protocols. Inconsistencies between laws and their enforcement underscore the need for improved coordination between regulatory frameworks and industrial activities. The government's efforts to promote circular economy concepts, like enacting sustainable levies and laws to decrease landfill consumption, show a commitment to fostering sustainability.

In addition, government rules promote sustainable practices and material utilisation through efforts like fuel efficiency star ratings and promoting re-treadability. This is supported by the requirements of Original Equipment Manufacturers -OEMs like vehicle companies on Rolling Resistance reduction, wet and dry grip improvements, and improved

tire life. While awareness levels vary across Europe and Asia, both regions recognise the importance of sustainable practices throughout the whole automotive tire production process. Government rules and regulations are crucial for promoting and ensuring the adoption and validation of sustainable rubber practices on a global scale, showcasing a collective dedication to promoting environmental preservation and ethical behaviour.

In conclusion, the interview responses highlight the various impacts of government policies on encouraging the adoption of sustainable materials and practices in the tire industry. Regulatory frameworks, incentives, and certification systems are essential for fostering sustainable growth. Collaboration among governments, industry stakeholders, and other relevant parties is crucial for achieving sustainable development goals. Experts from the European region as well as the Asian region agree that the awareness level is lower in the Asian region compared to the European region; however, the gap between these regions is getting closer due to initiatives from Asian governments, and tire industries, as Asia is one of the largest exporters of automotive tires to Europe (Crepaldi, 2023).

4.1.2 Question 02

What are the key challenges that tire producers need to overcome in order to incorporate sustainable materials?

Based on the 15 responses to this question, from the experts from Asian and Europe, once thing is clear that. when it comes to the usage of sustainable materials into tire, the manufacturers confront a number of significant challenges, and these challenges cover a

variety of different areas of research. When it comes to the initial stages of adoption, the availability and sourcing of sustainable resources emerge as significant obstacles. It is necessary to secure dependable sources while simultaneously navigating potential cost consequences from the beginning of the adoption process. The establishment of appropriate technologies that can incorporate these new materials into the design and manufacturing processes of tires presents yet another big problem. This endeavour calls for large investments in research and development as well as technological improvements. This may be done as a collaborative development with the recycler, ensuring the proper quality parameters.

A delicate balancing act is required in order to meet regulatory criteria without compromising on durability, performance, or cost. This requires extensive research and development activities. In addition, the market adoption process is complicated by the fact that consumer behaviours are always shifting, as well as the acceptance of potential cost increases and fluctuations in performance.

Tire manufacturers are required to establish efficient methods for handling used tires while following environmental standards in order to comply with the requirements of sustainability frameworks. This is because the disposal and reuse of tires and the treatment of waste tires within these frameworks also require considerable attention. Governments are imposing legislation such as EPR Extended Producer Responsibility to overcome these challenges. Also, recyclers also require consolidation, as they are currently disorganised.

In order to incorporate sustainable materials into the formulations of tires in compounding, it is necessary to complete excessive reassessment of the materials that are currently being used and to overcome resistance to change. It is a significant task to get the appropriate combination of materials while simultaneously ensuring ideal performance characteristics and avoiding any compromises in safety. Whether the material is used in its original form or recycled, it has the potential to influence performance parameters at the product level of a tire. Therefore, in order to achieve perfect equilibrium, it is necessary to do a thorough study in the areas of technical, quality, cost, and availability. Also, the performance enhancement of recycled material requires further study.

In particular, the difficulties that are associated with materials like carbon black, reclaim rubber, and crumb rubber bring to light the complexities that are involved in the integration of these materials. In the European market, there are few manufacturers that come-up with innovative products of carbon black that provide substantial reduction in rolling resistance by 1:1 replacement with conventional carbon black. However, the premium cost is a hindrance to implementation and regularisation of this material in tire production. Further, when it comes to polymers, comprehensive research and development activities are required in order to address concerns like the quality deterioration of the polymer during the recycling of the waste tire into crumb, reclaim, and other products. A few reclaim manufacturers are following surface treatment of the crumb rubber to reduce the property drop compared to virgin rubber. Again, this kind of research study is yet to be industrialised, and bulk production needs to be ensured before implementation.

In addition, there is still a considerable obstacle to overcome in terms of ensuring that sustainable materials match performance criteria while maintaining a balance between pricing and availability. The fact that consumers in various regions, such as Asia and Europe, have different levels of willingness to pay for sustainable goods and services complicates the equation even more. As Europe is a mature tire market, customers are willing to pay for sustainability, whereas in Asia, the customer mindset is different; those are not willing to pay more for sustainability.

Tire manufacturers will need to make significant investments in research and development, collaborate with stakeholders from across the industry, and effectively negotiate legislation in order to accelerate innovation and promote the use of sustainable resources within the automotive tire industry. For them to ultimately be successful in tackling these challenges, they will need to make these investments. These problems are able to be conquered with the backing of governments, in conjunction with recyclers and tire manufacturers.

4.1.3 Question 03

How does the utilization of sustainable materials by the tire industry impact the overall carbon footprint of the transportation sector, and to what extend?

The tire industry's utilisation of sustainable materials has a restricted capacity to substantially impact the transportation sector's total carbon footprint. Fuel combustion is the primary source of emissions in the transportation industry, with maritime and aviation

being the leading contributors. Road transport contributes around 20%. 80% of the 20% is attributed to the burning of fossil fuels. 30% of the 20% effect is attributed to the tire, which accounts for around 6% of the total contribution. This impact results from multiple factors that, throughout the lifecycle of tires, contribute to the reduction in greenhouse gas emissions.

Adopting sustainable resources decreases the carbon footprint of the raw materials used in tire production. This entails exploiting recycled or recovered resources, which inherently possess smaller carbon footprints than fresh materials, and obtaining tires with a diminished environmental impact.

Moreover, using sustainable materials typically results in a decrease in the durability of tires that are engineered for long-lasting performance and increased strength. This issue can be addressed by using specialty chemicals and incorporating certain recycling techniques to overcome the quality shortcomings throughout the innovative recycling process. Increased tire durability results in reduced tire changes, therefore lowering the total carbon footprint linked to tire manufacturing and disposal. Additional research is necessary to obtain the enhanced durability of tires made from sustainable materials.

Furthermore, including sustainable materials in manufacturing results in reduced energy usage and enhanced process efficiency. This results in reduced operational time, increased yields, and minimised waste output, all leading to a smaller carbon footprint in the manufacturing process.

In addition, products manufactured from sustainable materials lead to fuel efficiency in automobiles if they are specialty treated or converted materials, reducing carbon emissions associated with transportation. This is accomplished by employing highly processed and custom-made recycled materials to reduce rolling resistance.

Additionally, the possibility of reusing or recycling tires produced from sustainable resources supports a circular economy framework. This technique encourages the extended utilisation of resources, reducing the need for harvesting or manufacturing new raw materials.

Sustainable materials should have a minimal impact on the total carbon footprint of the transportation sector. Fuel combustion is a significant factor contributing to carbon footprint. Incorporating sustainable materials into tire manufacturing is an essential measure for reducing the environmental footprint of the transportation sector. Tire consumption can account for around 4~6% of the impact, given that tires contribute only 10~20% to the total impact.

4.1.4 Question 04

How do tire producers find a balance between using sustainable materials and complying with safety and performance regulations?

Tire companies confront an immense challenge when balancing the integration of sustainable materials in tire production with meeting safety and performance standards. Since safety parameters are mainly derived from structural materials and also from rubber

compounds, in the compound angle, since the usage of sustainable materials is relatively less in percentage, its contribution towards safety may be less. Strategic partnerships and innovative initiatives with recyclers and raw material producers can successfully overcome this challenge. Tire manufacturers could obtain sustainable materials that meet tight safety and performance specifications by forming firm partnerships with raw material producers and sources. Collaborating with stakeholders from both inside and outside of the company allows tire manufacturers to exchange ideas and resources to address difficulties while maintaining quality.

Leveraging both radical and gradual innovation throughout material utilization, product design, manufacturing methods, testing, and reuse/recycling is crucial for addressing the challenges of sustainability and regulatory compliance. Tire manufacturers need to conduct thorough research and development to collaborate with recyclers in order to find and confirm sustainable resources appropriate for tire production with sufficient availability. This collaboration combines the creative ideas of recycling companies, which are frequently limited in resources but abundant in inventive concepts, with the resources and knowledge of tire manufacturers, leading to significant breakthroughs.

Research and development experiments carried out internally by tire and sustainable material manufacturers are crucial in evaluating the feasibility of sustainable materials while maintaining safety and performance standards. The tire business is dedicated to safety, ensuring that safety standards are always maintained. Compromises in comfort and economic parameters like mileage and rolling resistance may be observed

based on the influence of sustainable materials. Stringent validation methods are in place to evaluate the performance and regulatory adherence of materials, compounds, and end products, guiding decisions on the proportion of sustainable materials used in tire manufacturing.

Tire manufacturers must comply with government rules that specify certain needs, leading to ongoing process enhancements and innovation. Research is concentrated on identifying the optimal blend of materials and manufacturing techniques to improve product efficiency while minimising environmental harm. Advancements in recycling used tires, like creating high-quality reclaimed rubber crumbs and activated crumbs, provide enhanced solutions to uphold safety and performance standards. Tire makers must adopt innovation, teamwork, and strategic planning to achieve a balance between sustainability and regulatory compliance in tire manufacturing.

4.1.5 Question 05

What are the potential avenues for technological advancements and innovations in the use of sustainable materials within the tire industry?

The tire industry is consistently pursuing technological developments and innovations to include sustainable materials into its manufacturing processes in order to improve product performance and minimise environmental effects. An essential aspect of this research is gaining a comprehensive understanding of how sustainable materials impact tire performance, durability, and manufacturing efficiency. Researchers and

engineers are working on altering product designs and improving material compositions to ensure that tires meet and surpass safety and performance standards while also integrating sustainable alternatives.

One potential path for progress involves adopting the concepts of the circular economy. The tire industry is investigating methods to repurpose and recycle materials such as polymers, fibres, fillers, and bio-derived resins. Research is concentrated on creating new technologies to recover and treat discarded tires, generating top-notch recycled materials that are appropriate for tire production. The industry tries to decrease waste and lower its environmental impact by completing the material utilisation loop.

Surface modification and treatment technologies have the ability to enhance the quality of recycled materials. Researchers attempt to improve the characteristics and performance of materials such as reclaimed rubber and carbon black by improving parameters such as time, temperature, mesh size, and reclamation agents. These developments facilitate the greater use of recycled materials in tire manufacturing while maintaining quality and safety standards.

Incorporating novel sustainable materials into tire production methods offers another path for advancement. Tire makers strive to improve tire performance and minimise environmental impact by using sustainable silica, graphene, and nano additions in their materials. It is essential to secure intellectual property rights (IPR) for products and patents associated with sustainable materials to promote collaboration and safeguard new solutions.

Implementing labelling standards and certification systems is crucial for increasing transparency and informing consumers about sustainable tire choices. These initiatives enable consumers to make well-informed decisions, encourage manufacturers to focus on eco-friendly products, and promote the widespread implementation of sustainable practices in the tire industry.

Government support, such as research grants, incentives, and regulatory frameworks, is crucial for fostering technological developments and innovations in sustainable materials in the tire business. Government-funded collaborative research and development initiatives can expedite advancements and support the shift to more sustainable tire production methods.

By concentrating on these prospective paths for technological progress and breakthroughs, the tire industry can attain increased sustainability, performance, and environmental responsibility in tire manufacturing procedures and products. The sector can lead to a more sustainable future through cooperation and dedication to innovation. This can be effectively done in collaboration with recyclers and government bodies. Irrespective of the region, the opinion was clear that the avenues are large, which needs to be exploited sufficiently to come up with innovative recycled products and procedures to maintain both performance and safety in the tire.

4.1.6 Question 06

What measures can tire manufacturers adopt to enhance transparency in their sustainable practices?

Based on the inputs from the 15 experts, improving transparency in the tire manufacturing sector on sustainable practices necessitates a thorough plan that includes engagement, authentication, communication, and accountability. This method should stress the active participation and cooperation of stakeholders from several sectors, including government regulatory bodies, consumers, supply chain partners, and unbiased third-party accreditation agencies. Tire manufacturers can match their sustainability efforts with industry norms and standards by engaging in open communication and forming relationships with stakeholders.

Certification and verification systems, such as internationally recognized standards like International Sustainability and Carbon Certification (ISCC), are crucial in supporting the validation of sustainability promises and the prevention of greenwashing. Adopting these certifications enhances the legitimacy of sustainability efforts and promotes transparency by offering concrete proof of compliance with strict environmental and social standards.

Transparent labelling, engraving, and branding methods are essential for expressing sustainability features to consumers, alongside formal certifications. Comprehensive labelling or engraving on tire goods, together with sustainability-focused marketing initiatives, educates buyers about the environmental advantages and durability of sustainable tires. Material traceability systems like MES, bar codes, QR codes, RFID, etc. can provide end to end traceability of the materials used. This will give consumers better transparency about the seriousness of the industry's commitment to sustainability. This

transparency enables customers to make well-informed decisions that are in line with their beliefs and sustainability preferences.

Enhancing sustainable practices in the tire sector requires transparency in reporting. Tire manufacturers should consistently release detailed sustainability reports that outline their environmental performance, encompassing measures like sustainable material usage, carbon footprint, and advancements towards sustainability objectives. Companies exhibit accountability and dedication to transparency in their business practices by providing this information to the public. Many tire manufacturers have already published their sustainability targets for 2030, which will obviously improve the transparency of their sustainability efforts to customers.

Government rules and industry standards are important factors that influence openness and accountability in the tire manufacturing sector. On the sustainability front, governments can propose voluntary as well as regulatory requirements for tires. Regulatory audits and compliance with industry sustainability standards guarantee that organisations fulfil their environmental obligations and achieve set criteria for sustainable practices.

Moreover, implementing standardised measurements like carbon footprints allows tire manufacturers to accurately measure and convey their sustainability initiatives. Companies exhibit openness and enhance accountability within the sector by voluntarily disclosing their carbon footprint and other information related to sustainability.

Communication and awareness campaigns are crucial for promoting openness to sustainable practices in the tire manufacturing industry. Companies can promote their

sustainability projects and engage stakeholders in discourse about sustainability and responsibility for society through proactive communication channels, including advertising campaigns and outreach to the public.

In conclusion, tire manufacturers can improve transparency in their sustainable practices, gain consumer trust, and promote positive change in the industry by adopting a comprehensive strategy involving stakeholder engagement, accreditation and verification, transparent disclosure, and effective communication.

4.1.7 Question 07

How do the European and Asian markets compare in terms of the adoption and utilization of sustainable materials in the tire sector?

The European Union is a pioneer in adopting sustainable materials in the tire industry and developing environmentally friendly laws. The EU's aggressive stance on sustainability, along with strict rules and incentives, has motivated tire manufacturers in the region to adopt environmentally friendly techniques and include sustainable materials in their products. The EU's focus on circularity, which encourages the reuse and recycling of materials, has motivated tire businesses to investigate new solutions and implement sustainable material practices comprehensively. Also, the infrastructural facilities for recycling in Europe are far advanced in comparison with facilities in the Asian region.

Regions like the United States and Japan show comparable progress in sustainability practices, with regulatory frameworks and industry initiatives resembling

those of Europe. These advancements operate as guiding principles for tire manufacturers in Asian markets, motivating them to harmonise their policies and practices with international sustainability norms. Asian markets are progressing rapidly in sustainability initiatives by utilising technological breakthroughs and collaborative collaborations, leveraging insights from more established economies.

Europe is at the forefront of adopting sustainable materials, but Asian economies, especially India, are quickly following suit. They are initially focusing on European markets and progressively shifting towards sustainable practices in their local markets. Asian tire manufacturers are starting to include environmentally friendly components into their products, although they are mindful of costs. European markets show higher sustainability maturity compared to Asian markets, with a stronger awareness and readiness to pay extra for sustainable tires.

European tire manufacturers are making strong commitments to sustainability by promising to considerably increase the use of sustainable materials in their products. These commitments are widely supported in the industry, since large companies are establishing ambitious goals to use recycled materials and decrease carbon emissions. Europe's strong regulations and increased consumer awareness help make the region a top global leader in producing environmentally friendly tires due to its advanced sustainability standards.

Asian markets are at varied phases of their sustainability journey, with differing levels of knowledge and implementation across countries. Asia is the primary user of natural rubber (NR), while synthetic materials are more prevalent in Europe due to regional

preferences and resource availability. Asia has made progress; however, there is a noticeable difference in sustainability maturity compared to Europe. European markets have higher recycling efficiency and public awareness.

In conclusion, based on the opinions of the experts from Asia as well as Europe, Europe leads in sustainability adoption and awareness, while Asian markets are quickly advancing due to a rising acknowledgment of the significance of green practices and the necessity to comply with global norms. Asian tire makers are investing in sustainable technology and practices with support from regulations and international collaborations, positioning the area to challenge European markets and become a significant participant in the global sustainable tire sector. Although European and Asian markets differ, they both aim to decrease environmental impact, enhance resource efficiency, and fulfil changing customer demands for sustainable products. The increasing global awareness of climate change and environmental deterioration is anticipated to lead to a higher demand for environmentally friendly tires worldwide. Tire manufacturers in Europe and Asia need to develop, collaborate, and invest in sustainable technology to remain competitive in a fast-evolving industry. The tire industry can collectively progress towards a more sustainable and resilient future by exploiting the assets of each region and tackling unique challenges.

4.2 Patents Search and Sustainability Report Data Analysis

4.2.1 Patents Search

Sustainability has become an important concern in various businesses, including the tire manufacturing sector. Tire producers in the automobile industry are increasingly

using sustainable materials in order to reduce their environmental impact. As a part of this study, a patent search was carried out using the WIPO Patentscope database as shown in figure 09 (https://patentscope.wipo.int/search/en/search.jsf) to investigate the most recent advancements and trends in sustainable materials in the tire industry. The search concentrated on 23 specific keywords, as given in Table 02, associated with sustainable materials, to pinpoint the regions at the forefront of innovation in this area. This has been discussed with industry experts to finalise the key words to conduct the patent search. Patents were collected and analysed to compare the inventor's nationality, company applied, and applicability in different regions. There were 34 patents from Asia, 6 from the European Union, and the rest from other parts of the world. They were selected based on the nature of the invention and its importance to sustainability and the tire industry. Out of the 47 patents found, 12 were particularly related to tire companies. The below image shows the Wipo Patentscope website user interface.

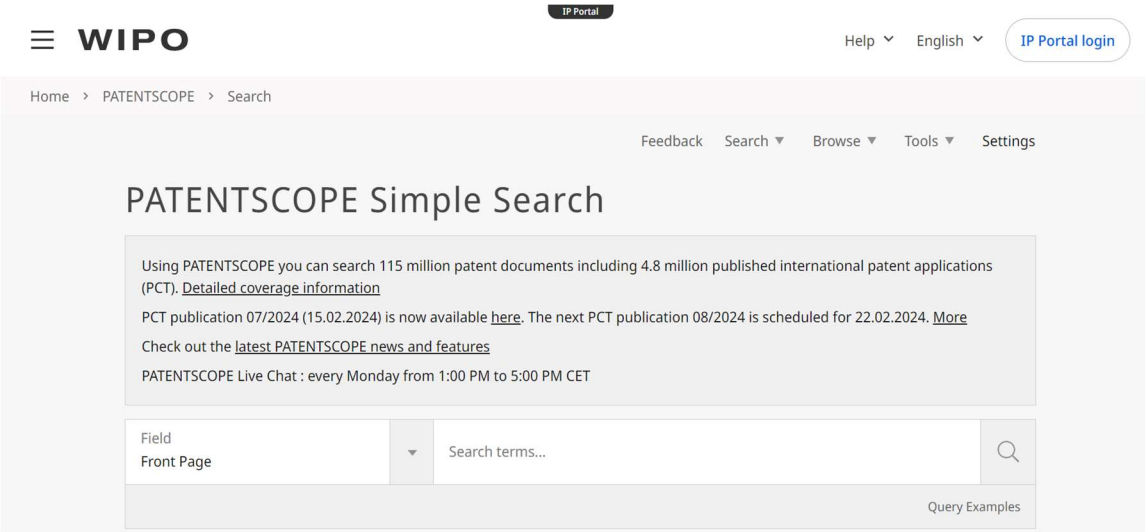


Figure 09: WIPO - Search International and National Patent Collections (Source: Wipo.int, 2019)

For finalising the keywords for the patent search, industry experts' opinions were sought. The below given table 02 lists the key words used for patent searches.

Sl No	Keywords for Patent search
1	Sustainable Tyre
2	Sustainable Tire
3	Sustainable Tire/Tyre Materials
4	Recycled Tire/Tyre Materials
5	Eco-friendly tire materials
6	Green tire technology
7	Renewable tire components
8	Recycled tire materials
9	Biomass-based tire compounds
10	Environmentally friendly tire production
11	Tire recycling innovations
12	Low Rolling Resistance Compounds for Tire
13	Low-impact tire manufacturing
14	Biodegradable tire materials
15	Natural rubber alternatives
16	Sustainable elastomers
17	Eco-conscious tire compounds
18	Green tire design patents
19	Circular economy in tire industry
20	Waste tire utilization patents
21	Sustainable fillers for tires
22	Eco-friendly tire tread formulations
23	Reclaimed rubber technology patents

Table 02: Keywords for Patent Search.

For comparison and analysis purposes, a list of Asian and European countries was collated and is given in Tables 03 and 04 below.

Sl No	**WIPO Abbreviation**	**Country Name**
1	AF	Afghanistan
2	AZ	Azerbaijan

3	BD	Bangladesh
4	BH	Bahrain
5	BT	Bhutan
6	CN	China
7	CY	Cyprus
8	IL	Israel
9	KG	Kyrgyzstan
10	KH	Cambodia
11	KW	Kuwait
12	KZ	Kazakhstan
13	LK	Sri Lanka
14	MM	Myanmar
15	PH	Philippines
16	PK	Pakistan
17	QA	Qatar
18	SA	Saudi Arabia
19	SG	Singapore
20	TH	Thailand
21	TJ	Tajikistan
22	TL	Timor-Leste
23	TM	Turkmenistan
24	TR	Turkey
25	UZ	Uzbekistan
26	YE	Yemen

Table 03: List of Asian countries for Patent Search

Sl No	**WIPO Abbreviation**	**Country Name**
1	AD	Andorra
2	AT	Austria
3	BA	Bosnia and Herzegovina
4	BE	Belgium
5	BG	Bulgaria
6	BY	Belarus
7	CH	Switzerland
8	EE	Estonia
9	HR	Croatia

10	HU	Hungary
11	IE	Ireland
12	IS	Iceland
13	LI	Liechtenstein
14	LT	Lithuania
15	NL	Netherlands
16	NO	Norway
17	PL	Poland
18	PT	Portugal
19	RO	Romania
20	RS	Serbia
21	SE	Sweden
22	SI	Slovenia
23	SK	Slovakia
24	SM	San Marino
25	UA	Ukraine

Table 04: List of European countries for Patent Search

Based on the analysis of the data, the below table 05 provides a summary of the patent search.

Region	Inventor's Nationality	Applicable EU/US	Applicable ASIA
ASIA	34	7	27
Europe	6	1	6
US/Rest of World	7	2	5
Total	47	10	38

Table 05: Summary for Patent Search

The conclusion that can be drawn from the patent search based on the specified key words is that a greater number of innovators originate from Asia. This is the case regardless of the level of maturity that the European region possesses in terms of sustainability. 25%

of patents that were invented by Asians are applicable to regions of Europe and the United States. On the other hand, one hundred percent of the European patents that were discussed are applicable in the Asian region in addition to the European Union and the United States. The search for patents revealed a number of interesting findings, one of which was that the tire business is responsible for 25% of all inventions that are related to environmentally friendly materials, as the initial assumption was that raw material suppliers were considering the business.

4.2.2 Sustainability Reports Review

The researcher analysed sustainability reports of tire companies from Asia and Europe to provide detailed information on their dedication to environmental stewardship, social responsibility, and economic sustainability. As a representation, tire majors like Continental AG, Michelin, Goodyear, Bridgestone, MRF, CEAT, Yokohama, BKT, JK, and Apollo Tires were considered for sustainability report review. Tire companies globally are following the UN guidelines for the 17 Sustainable Development Goals when drafting their sustainable targets (United Nations, 2015). The 17 sustainable development goals are shown in Figure 34.

Both the European and Asian companies incorporated their action plans for achieving the 17 sustainable development goals into their sustainability practices. All these company reports are primarily covering the following areas

- Greenhouse Gas GHG Emissions
- Carbon Neutrality Targets.

- Views on Circular Economy.
- Responsible Value Chain
- Good Working Conditions
- Sustainable management practices.

Figure 34: The 17 Sustainable Development Goals (Source: United Nations, 2015)

The sustainability reports of tire manufacturing majors cover the UNs SDGs in detail, including targets and action plans. Few of the tire manufacturers from the Asian region priorities efforts to decrease carbon emissions, preserve natural resources, and promote community involvement. Some tire manufacturers in the Asian region keep sustainability related activities in crunched form. Figure 33 represents the action plans of Apollo Tires from India.

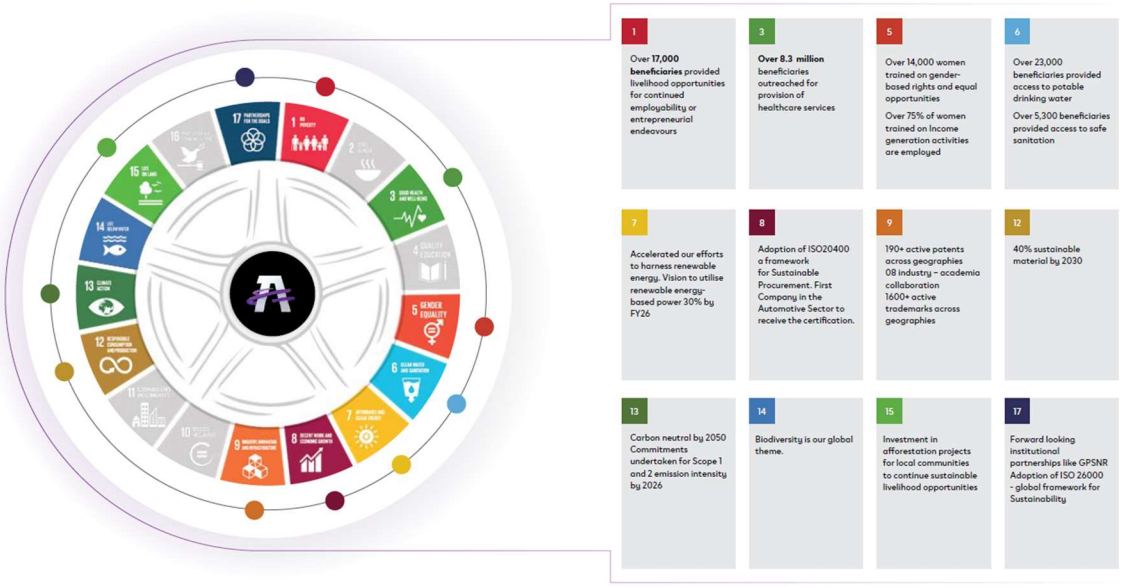


Figure 33: Apollo Tyres Ltd. Sustainability Report 2022-23 (Source: Apollo Tyres Ltd, 2023)

To reduce environmental effects, tire companies cover the entire product lifecycle, from obtaining raw materials to disposing of the used tire, with an emphasis on decreasing energy use, water usage, and waste production. Asian organisations promote sustainable material sourcing procedures, such as obtaining natural rubber and recycled materials, and

engage with local people through social welfare programmes and partnerships with non-profit organisations. Asian tire firms are trying to establish precise sustainability goals and monitor key performance indicators to assess their advancement over time. When comparing the sustainability reports of tire companies globally, even though some are covering all the necessary 17 SGDs in their goals and reports, there is still scope for improvement with respect to sustainability. Figure 35 shows the incorporation of UN SDGs into the company's core values and purpose.

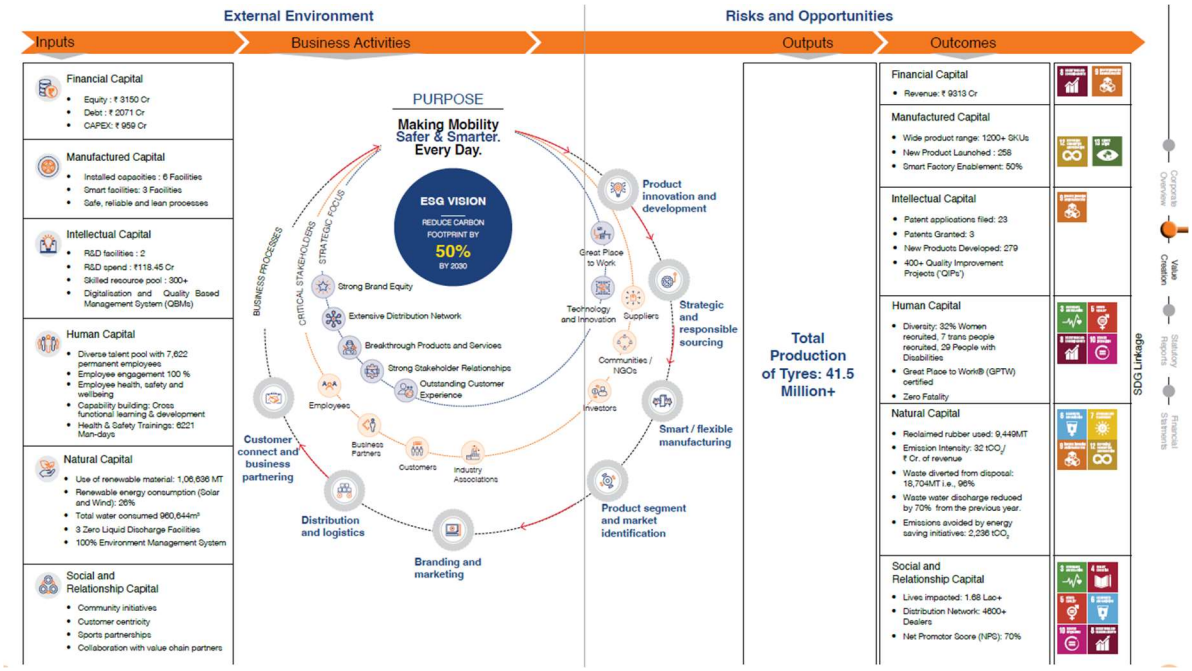


Figure 35: CEAT Tyres. Sustainability Report 2022 (Source: CEAT Tyres, 2022)

Figure 30 shows the targets set by Bridgestone Tires. These companies are taking the UN SDGs seriously and transforming their action plans to meet these targets to provide sustainable tires and future mobility.

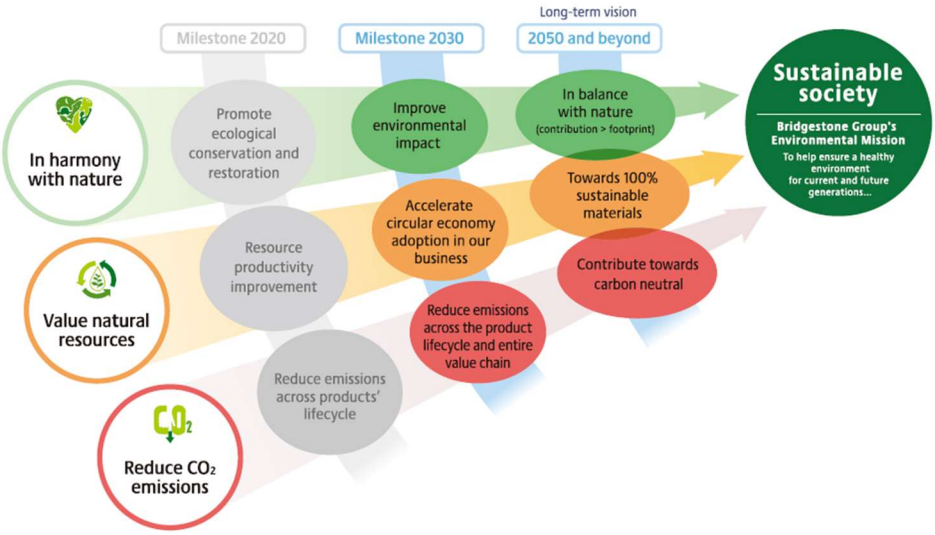


Figure 30: Bridgestone Group Milestone 2050 (Source: Bridgestone, 2021)

Figure 31 gives an idea of the carbon dioxide emission reduction targets taken by Bridgestone Tires; this reference is taken from the sustainability report of the company.

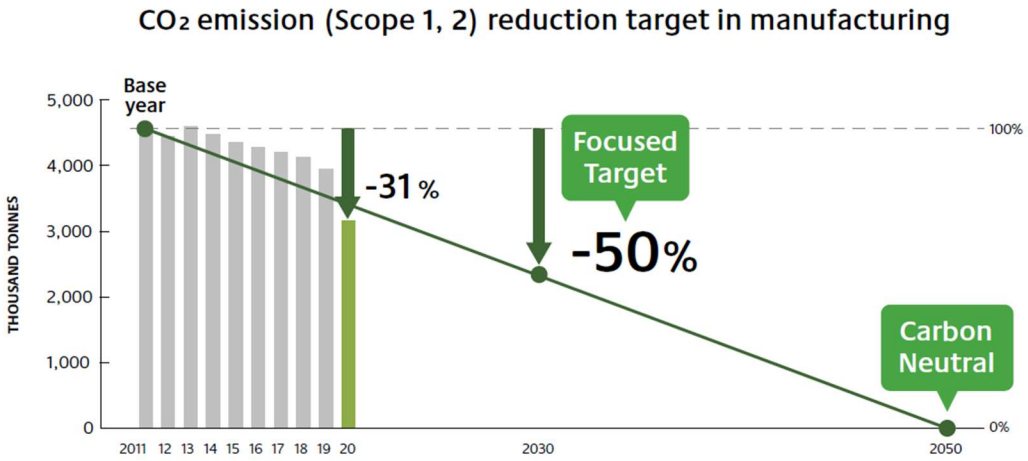


Figure 31: Bridgestone Group CO2 emission Scope 2050 (Source: Bridgestone, 2021)

On the other hand, European tire manufacturers are known for their leadership in sustainability, harnessing sophisticated technologies and partnerships to promote environmental and social advancements. They promote circular economy concepts by demonstrating resource efficiency, product durability, and end-of-life recycling. They focus on sustainability by implementing strategies to achieve carbon neutrality and reduce greenhouse gas emissions through investments in renewable energy, energy-efficient technologies, and carbon credit schemes.

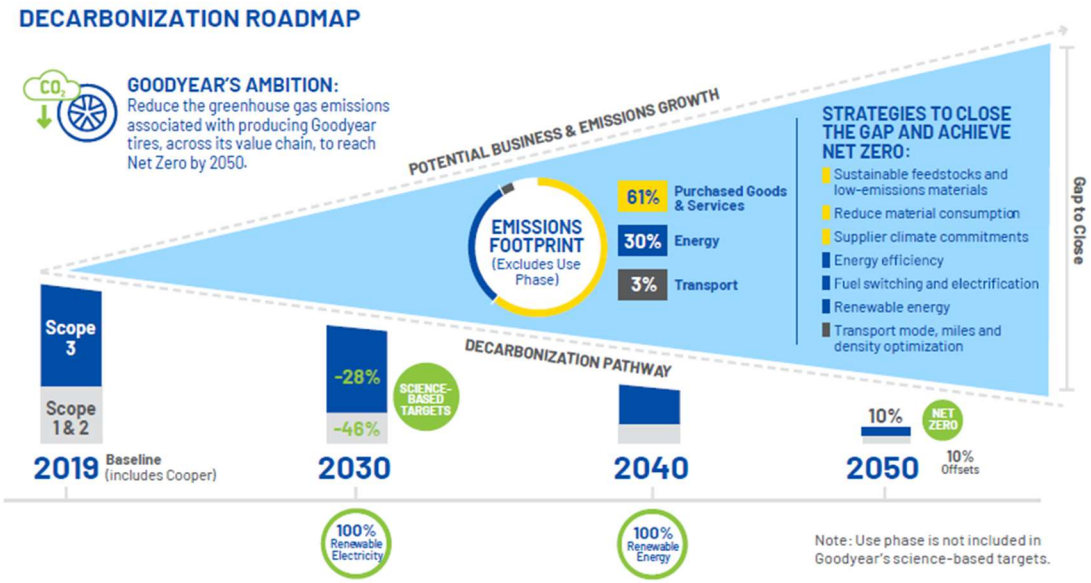


Figure 32: Goodyear Tire Corporate Responsibility Report 2022 (Source: Goodyear, 2022)

European companies stress openness and accountability in their sustainability reporting by subjecting themselves to independent audits and third-party certifications to verify the truth and reliability of their statements. Stakeholder involvement is a crucial

element of their sustainability strategy, emphasising the importance of communication, addressing issues, and integrating stakeholder input into decision-making.

Asian and European tire manufacturers show a significant dedication to environmental obligation, social welfare, and economic sustainability in their sustainability reports. These companies aim to inspire confidence among stakeholders, encourage good change in the industry, and contribute to a more sustainable future by openly recording their projects, progress, and issues. To conclude, even though many of the Asian tire manufacturers are covering many of the UNs, SDGs in their sustainability reports, there is still scope for improvement to reach the level of sustainability reporting and practices in Europe and other parts of the world. The company's targets for initiatives like carbon neutrality and zero emissions with a limited time plan give customers and other stakeholders confidence in sustainability.

4.3 Survey Data Analysis

The researcher prepared a detailed survey consisting of 20 questions. Google Forms was used as the data collection tool. This helped the researcher to circulate this survey through various social media platforms to gather responses. The survey included qualitative and quantitative questions. Respondents were first classified into three primary groups based on the geography, European, Non-European, and Asian. This division facilitated a comprehensive comprehension of regional viewpoints and methodologies in the tire business and its associated industries.

Respondents were segmented based on their occupation into four categories: Tire industry, non-tire industry (manufacturing other rubber goods), Raw Material

Manufacturers for Tire and Rubber, and End users of Tires. This thorough analysis allowed for a more extensive investigation of the many viewpoints and experiences present in the sector, revealing distinct obstacles, patterns, and advancements that are pertinent to each segment.

The quantitative analysis applied simple mathematical techniques to examine numerical data obtained from survey replies. This method offered valuable insights into trends and patterns in the dataset, enabling the researcher to draw conclusions based on evidence from the data

On the other hand, the qualitative analysis entailed a thorough investigation of open-ended responses and the qualitative information obtained from the survey. The researcher analysed this to discover prevalent patterns, insights, and views shared by participants. The qualitative method offered insightful context, detailed descriptions, and a sophisticated grasp of the elements affecting decision-making, obstacles encountered, and possibilities for enhancement in the business.

The researcher acquired a comprehensive knowledge of the research problems by integrating both quantitative and qualitative approaches. Quantitative research offered empirical evidence and numerical patterns, while qualitative analysis enhanced the findings with contextual comprehension and detailed insights from participants. Employing a mixed-method approach enhanced the credibility and dependability of the research results, providing a thorough view of the acceptance, challenges, and possibilities for sustainable practices in the tire industry among various locations globally.

All the 20 questions responses are captured and analyzed for keeping the objective of answering the research questions.

4.3.1 Survey Question 1

Country you are residing?

The inquiry about the respondent's country of residence in a survey is important. It helps to provide context to the responses by providing an understanding of regional variations in attitudes, behaviours, and preferences. This data enabled the researcher to comprehend how variables like culture, socioeconomic conditions, and regulatory contexts impact the viewpoints of the participants.

The question about the nation of residency allows researchers to analyse data by geographical regions, making it easier to compare different countries or regions. Comparing data can uncover patterns, trends, and variations that may not be obvious when looking at data individually.

It is crucial to comprehend the geographical distribution of respondents to ensure the survey findings are representative and can be generalised. The researcher could gain a more thorough picture of the topic being studied and draw more informed conclusions by collecting replies from several countries or locations. It is crucial to include the question about the nation of residency in a survey to provide context for responses, enable comparative analysis, and enhance the reliability of study findings.

The researcher was able to gather a total of 327 responses globally using Google Forms as the tool. A pie chart is given in Figure 10, representing the same

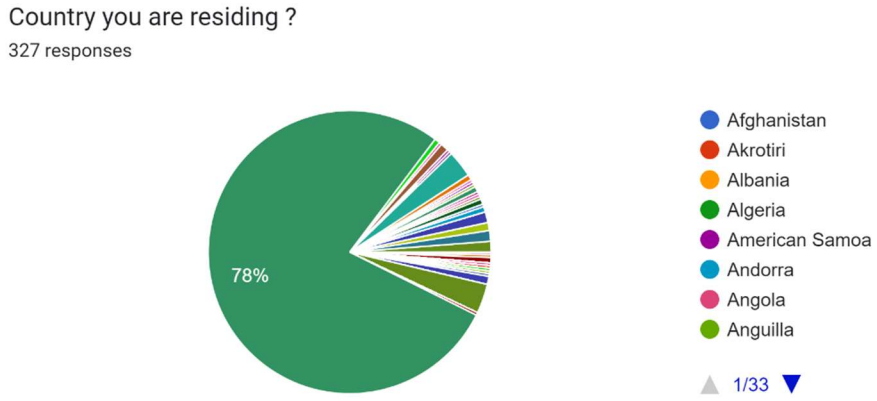


Figure 10: Survey response to question 01 Country of residence.

4.3.2 Survey Question 2

Do you think sustainable materials will become the norm in the tire industry in the future?

Sustainable materials are expected to become the norm in the tire industry in the future. Increased environmental concerns, more stringent legislation, rising consumer demand for environmentally friendly products, technological advancements enabling sustainable alternatives, and industry-wide cooperation are driving the change. The shift towards sustainability is evident, and tire makers are expected to include more environmentally friendly materials into their operations, despite the time and resources required for the transition.

A total of 332 responses were received for this question on a global level. A pie chart representing the response is given in Figure 11. About 96% of the respondents

globally were in agreement that sustainable materials will become the norm in the tire industry in the future, whereas only 4% were not thinking in that direction.

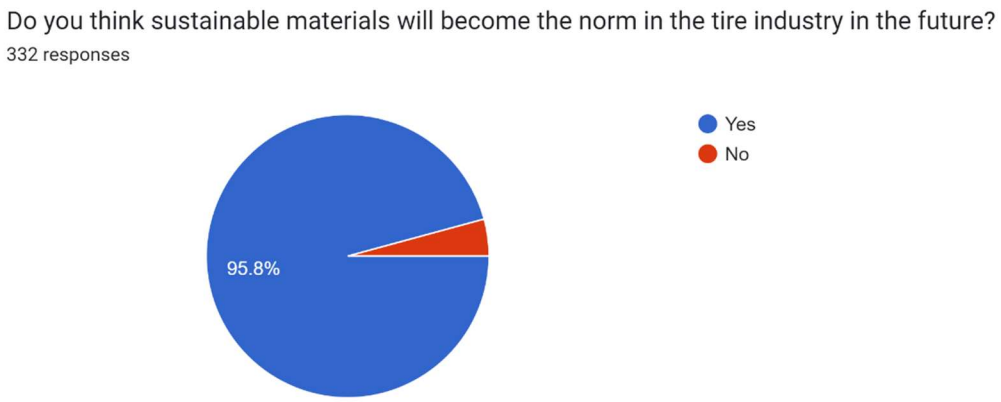


Figure 11: Survey response to question 02, sustainable materials will become the norm in the tire industry in the future?

4.3.3 Survey Question 3

Which tire market is leading the adoption of sustainable materials usage?

The researcher incorporated this question into the survey to provide an overview of sustainable material usage and practices in the tire industry by identifying geographies and markets leading to the use of materials that are sustainable. This comprehension acts as a standard for evaluating advancements towards sustainability goals and guides plans for accommodating in different areas inside the tire industry. The question assists in analysing the factors influencing the adoption of sustainable materials in individual markets, such as governmental frameworks, consumer demands, industry initiatives, and technological breakthroughs. The researcher could analyse these characteristics to identify important influences on sustainability. Comparing different geographical locations assisted the

researcher in pinpointing differences, patterns, and effective strategies that can guide future decision-making and policy creation to promote sustainable goals throughout the industry. This survey question is essential for evaluating present practices, comprehending underlying factors, and pinpointing potential to enhance sustainability in the tire industry.

Figure 12 represents the response to survey question 3 in a graphical pie chart. A total of 329 responses were received globally, and out of those, 73% of the respondents agreed that Europe is leading the adoption of sustainable materials and practices, whereas 27% believed that Asian countries are leading the sustainable material usage and practices.

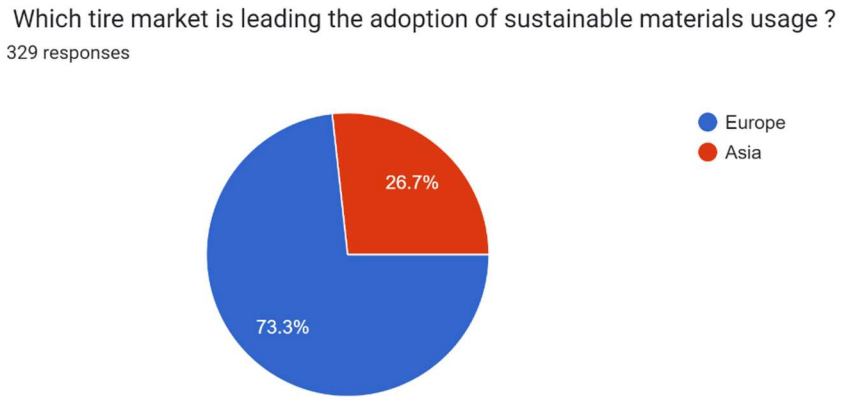


Figure 12: Survey response to question 03, Which tire market is leading the adoption of sustainable material usage?

4.3.4 Survey Question 4

As an end user are you willing to buy a tire with sustainable materials at a higher cost?

The question of whether end users are willing to purchase tires made from sustainable materials at higher costs is crucial to this research. The study directly evaluates consumer views and preferences towards sustainable products in the tire segment. Studying customer readiness to pay a premium for tires produced with sustainable materials offers useful insights on market demand and the possible acceptance of eco-friendly products. This information is essential for tire manufacturers and policymakers who want to assess the feasibility and commercial prospects of sustainable tire choices.

The response to this question reveals the importance customers place on sustainability when making purchasing decisions. It assists in determining if consumers value environmental factors and are open to balancing cost and sustainability. This insight guides marketing strategies, product positioning, and pricing choices for sustainable tires, helping companies connect their offers with customer preferences and market trends efficiently. The question assesses the awareness and education level of end users about the environmental and social benefits of sustainable materials in tires. It acts as a gauge of consumer involvement in sustainability matters and can direct initiatives to increase awareness and encourage environmentally conscious purchase habits. The responses to this question provide practical data for tire producers, retailers, and policymakers to personalize their strategies, products, and communication methods to align with consumer demand for sustainable solutions, while also considering pricing and value proposition.

A total of 332 responses were received for this question, and irrespective of the initial perception of the researcher, on no-willingness to purchase tires with sustainable

materials at a higher price, 59% of the global respondents expressed their willingness to buy tires that are made of sustainable materials. Whereas 41% of the total respondents were no-willing to purchase tires that are made of sustainable materials at a higher cost. Figure 13 provides a pie chart representing the same.

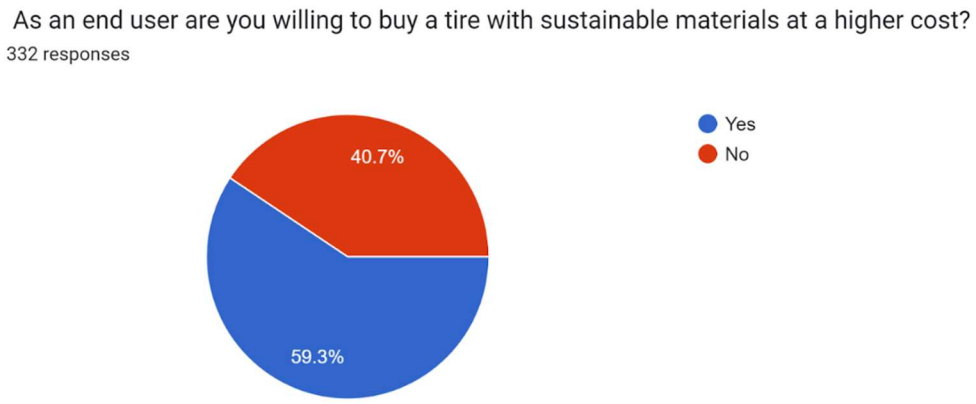


Figure 13: Survey response to question 04, end user willingness to buy a tire with sustainable materials at a higher cost.

4.3.5 Survey Question 5

Do you think Asian governments are making policies in promoting sustainable material usage?

This question is crucial in the analysis of sustainable materials in the tire industry. It is an important indication of how regulations impact sustainable practices in the Asian market. The question offers useful insights regarding the effectiveness of current policies and possibilities for change by assessing perceptions of governmental support. Industry answers aid in pinpointing obstacles to compliance and informing policymakers of

stakeholder requirements, enabling the creation of focused measures to encourage sustainable practices. The question promotes discussion between industry stakeholders and policymakers, encouraging cooperation to achieve common sustainability objectives. It acts as a catalyst for making well-informed decisions and taking concerted action to promote sustainability in the Asian tire sector.

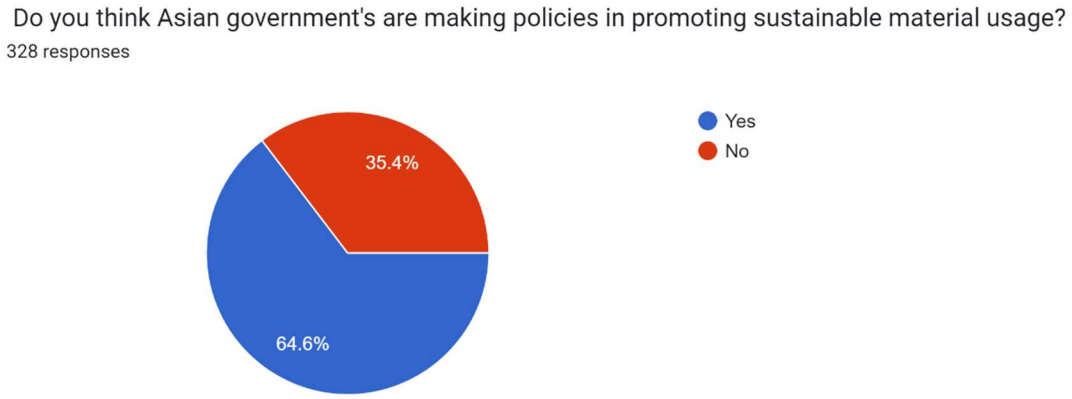


Figure 14: Survey response to question 05, Do you think Asian governments are making policies in promoting sustainable material usage?

A total of 328 responses were received for this question, and out of those, 65% globally believed that Asian governments are making policies to promote sustainable material usage. The remaining 35% of respondents believed that Asian governments were not making policies to promote sustainable material usage in the tire industry. Figure 14 represents the pie chart of the response.

4.3.6 Survey Question 6

Do you think the usage of sustainable raw materials can affect the tire performance and quality?

The question is of utmost importance in this research on sustainable materials in the tire industry. This question helped the researcher critically examine how sustainable raw materials affect tire performance and quality. Answers to this question offer vital insights into how the industry views things, which helps in making decisions about material selection, product design, and manufacturing techniques. It is crucial to comprehend the possible compromises between sustainability and performance in order to balance environmental goals with consumer expectations for safety, durability, and reliability. Addressing performance and quality concerns can enhance consumer trust and confidence, promote the use of sustainable tires, and further environmental sustainability in the tire sector.

The researcher received 326 responses to this question, and the major takeaway from the responses is that 43% of the respondents globally have no idea about sustainable material usage and the effect on performance and quality of the tires. 34% of the respondents believed that the use of sustainable materials could enhance the performance and quality of the tire. 23% of the respondents believed that performance and quality deteriorated with the use of sustainable materials in tires. Figure 15 represents the pie chart of the response.

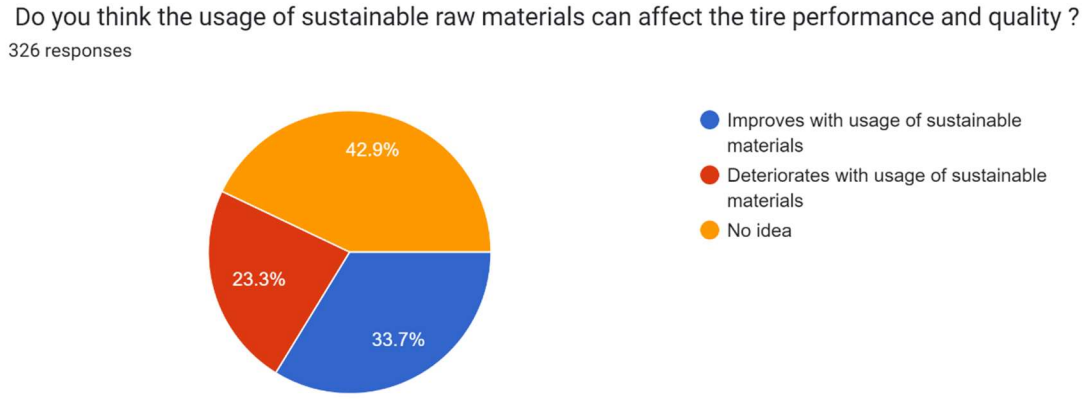


Figure 15: Survey response to question 06, Do you think the usage of sustainable raw materials can affect the tire performance and quality?

4.3.7 Survey Question 7

Do you think tire producers can ensure the tires made from sustainable materials will have both durability and excellent performance?

The question of whether tire manufacturers can guarantee that tires developed from sustainable materials will possess both longevity and exceptional performance is an important on in this study of sustainable materials in the tire industry. This is important; because, the researcher is investigating the perceived abilities of tire manufacturers to produce high-quality, long-lasting tires using sustainable materials. Responses to this question offer vital insights into stakeholder's trust in the industries capability to uphold or improve tire performance as they shift to more environmentally friendly materials. Comprehending how consumers see durability and performance is crucial for dealing with their worries, guiding product development plans, and promoting the implementation of

sustainable methods in tire production. This question encourages conversations about technological improvements, innovation, and quality assurance measures needed to ensure that sustainable tires meet or surpass industry standards and customer expectations

On a global level, 330 responses were received for this question, and 72% believed that tire manufacturers are capable of making tires with sustainable materials, ensuring both durability and excellent performance. 23% of respondents had no idea about this. Only 5% of the respondents believed that tire manufacturers could not maintain both durability and excellent performance while using sustainable materials. Figure 16 represents a pie chart of the global response.

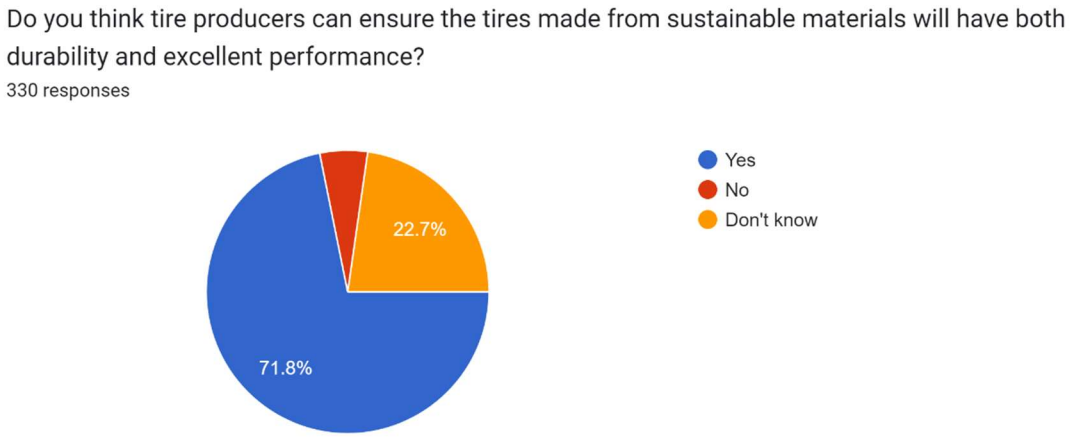


Figure 16: Survey response to question 07, Do you think tire producers can ensure the tires made from sustainable materials will have both durability and excellent performance?

4.3.8 Survey Question 8

Do you think the usage of sustainable materials can reduce the environmental impacts?

This question is important in the present study of the analysis of sustainable materials in the tire industry. This study examines the environmental advantages of using eco-friendly materials in tire production. It is essential to comprehend stakeholders' views on the environmental effect reduction potential of sustainable materials to evaluate the industry's sustainability initiatives. Answers to this question provide important perspectives on stakeholder knowledge and opinions regarding environmental sustainability in the tire sector. It educates governments, business leaders, and consumers on how sustainable materials can help reduce environmental impact by lowering carbon emissions, preserving natural resources, and eliminating waste.

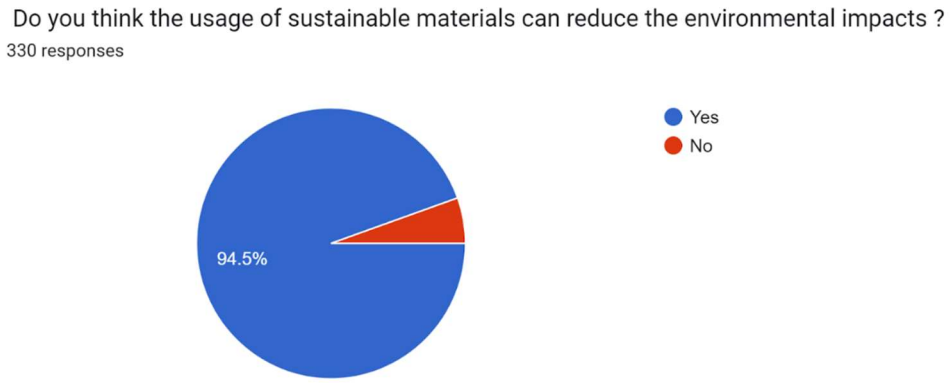


Figure 17: Survey response to question 08, Do you think the usage of sustainable-materials can reduce the environmental impacts?

A total of 330 respondents answered this question, and the majority of 95% believed that the usage of sustainable materials can reduce the environmental impact. Only 5% believed that sustainable material usage could not reduce environmental impact. The above figure 17 represents the pie chart of the responses globally.

4.3.9 Survey Question 9

According to you, what are the top 5 sustainable materials used in tire industry?

The question is essential for understanding stakeholders' views and knowledge about sustainable materials used in tire manufacturing. The question intends to assess respondents' knowledge and awareness of green alternatives to traditional tire components by offering them a choice of sustainable materials usually employed in the industry. Studying respondents' selections can uncover common patterns and preferences related to sustainable materials, aiding in the recognition of which choices are seen as the most feasible and influential in terms of sustainability. The inquiry aims to showcase the range of sustainable materials that can be used for tire production, increasing awareness and educating stakeholders about the different sustainable choices. The choices made by respondents can provide valuable information to tire manufacturers, policymakers, and researchers regarding the effectiveness and popularity of various sustainable materials. This data can help guide future efforts and investments in sustainable tire manufacturing processes.

Out of total 332 responders, 326 given their views to this question. 80% responder's select natural rubber in the top position followed by RcB 68%, Reclaim rubber 66%, Rubber Crumb 60%, Natural oil, derivatives and fabrics at 55% and 51% selected Silica.

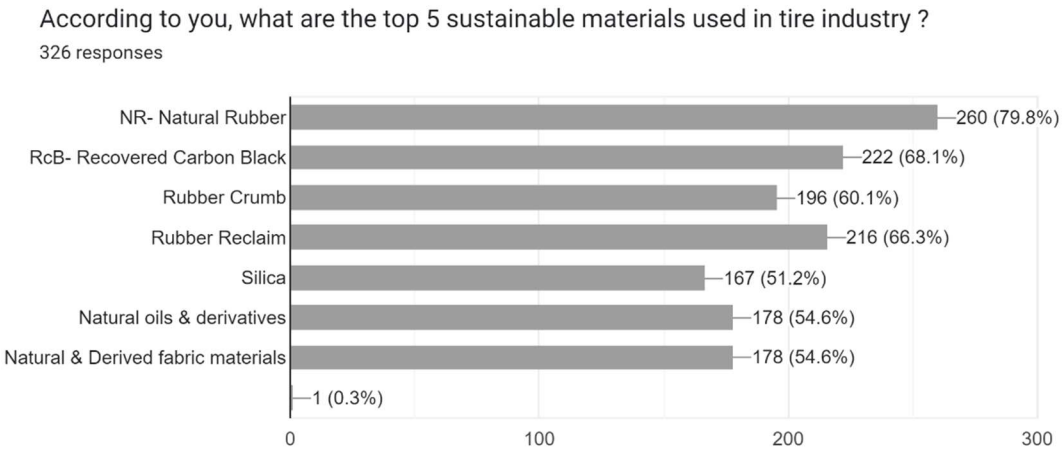


Figure 18: Survey response to question 9, According to you, what are the top 5 sustainable materials used in tire industry?

4.3.10 Survey Question 10

Do you think the use of sustainable materials in the tire industry impacts the overall carbon footprint of the transportation sector?

This question seeks to reveal insights into the perceived environmental advantages of adopting eco-friendly materials in tires by asking respondents about their opinions on the connection between tire sustainability and the transportation sector's carbon footprint. Answers to this question can reveal stakeholders' comprehension of the relationship

between tire manufacturing methods and transportation-related greenhouse gas emissions. The topic asks respondents to think about how sustainable materials might help reduce carbon emissions across the full lifespan of tires, from production to disposal. Insights obtained from the viewpoints of respondents helped the researcher determine how beneficial the use of sustainable materials is in reducing the transportation sector's carbon footprint.

330 responses were received for this question globally. 90% believed that the use of sustainable materials in tire manufacturing could reduce the carbon footprint of the transportation sector. The researcher will be analysing this question later in comparison with the direct interview responses of industry experts. The below given Figure 19 represents the pie diagram of the responses.

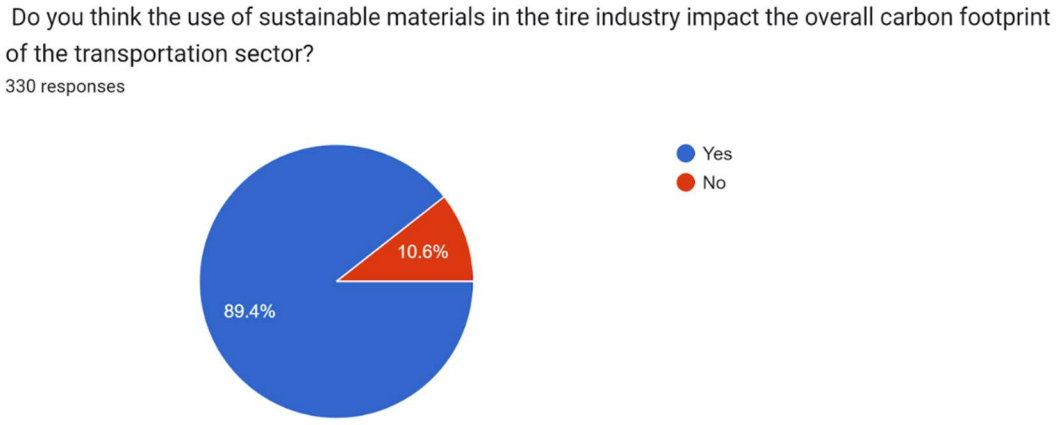


Figure 19: Survey response to question 10, Do you think the use of sustainable materials in the tire industry impacts the overall carbon footprint of the transportation sector?

4.3.11 Survey Question 11

Do you think there is a difference in the level of demand for sustainable tires between European and Asian markets?

This question is essential for comprehending geographical variations in customer preferences and market dynamics related to sustainable tires in the present research. This question examines how respondents perceive differences in demand between European and Asian markets, offering useful insights into regional trends and preferences for sustainable products. This question aims to determine if consumers in various locations consider sustainability when buying tires and if there are significant differences in environmental awareness between European and Asian markets. Moreover, comprehending these regional variations in demand helped the researcher provide guidance to tire manufacturers and policymakers in developing personalised marketing tactics, product offerings, and sustainability measures to cater to the distinct preferences and expectations of customers in each market. This question's insights can help bridge awareness of environmental deficiencies and promote sustainable practices globally, leading to increased use of eco-friendly tires and enhanced environmental sustainability in the automotive sector.

The researcher received 329 responses for this question globally, and out of those, 88% believed that there is a level of difference in the requirements of sustainable tires. The researcher substantiated this with the opinions of experts, during the direct interview, which revealed that the European market is in high demand for sustainable tires, while the Asian market is in low demand. Figure 20 represents a pie diagram of the responses.

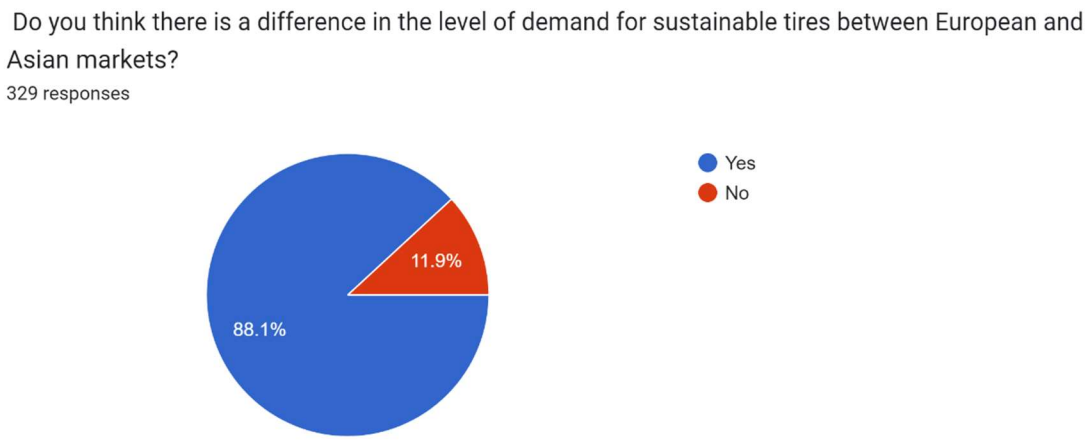


Figure 20: Survey response to question 11, Do you think there is a difference in the level of demand for sustainable tires between European and Asian markets?

4.3.12 Survey Question 12

How important is it for tire manufacturers to communicate their sustainability efforts to consumers?

This question is essential to determining the importance of clear communication regarding sustainability activities in the tire industry. The survey revealed consumer expectations and preferences about business transparency and environmental responsibility by asking respondents for their perspectives on the significance of such communication. Tire manufacturers may adjust their communication strategy by understanding the significance of conveying sustainability initiatives to consumers, and ensuring an effective representation of their dedication to sustainability. Transparent communication builds confidence and credibility with consumers, helping them make well-informed purchasing

decisions that match their beliefs and preferences for sustainable products. Tire manufacturers may distinguish their brand in a competitive market, attract environmentally aware consumers, and foster brand loyalty by promoting their sustainability initiatives.

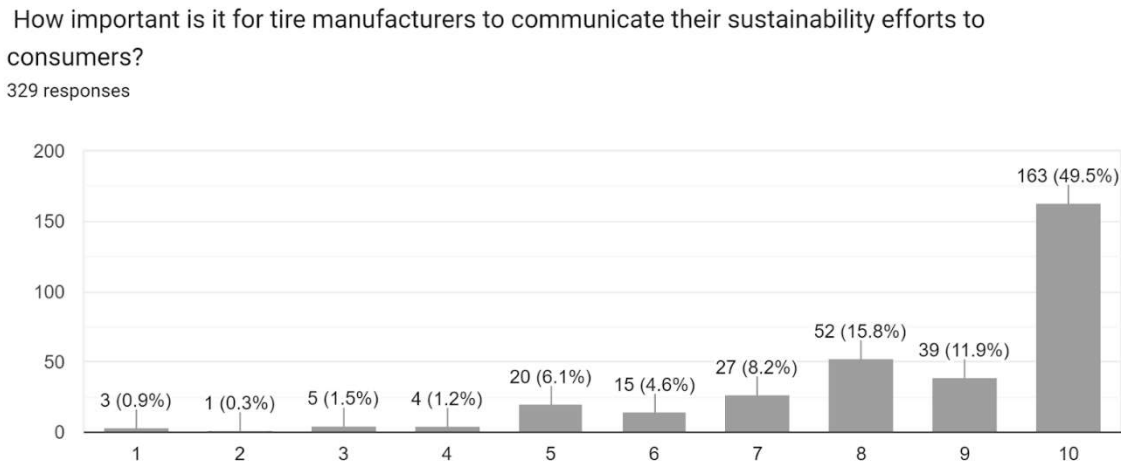


Figure 21: Survey response to question 12, How important is it for tire manufacturers to communicate their sustainability efforts to consumers?

The above Figure 21 gives a graphical representation of the responses received globally. About 50% of the respondents believed that it was most important to communicate sustainability initiatives to customers. More than 90% of the respondents were given 6 or higher ratings. The conclusions drawn from this question could help tire manufacturers improve their marketing and communication strategies to effectively promote their sustainability efforts and build more consumer trust and engagement with their brand.

4.3.13 Survey Question 13

Do you think tire recycling and retreading play a role in promoting sustainability in the tire industry?

This question is helpful for comprehending the impact of recycling and retreading procedures on promoting sustainability in the tire industry. The survey results could reveal the perceived efficacy of tire recycling and retreading initiatives in decreasing environmental impact, preserving resources, and lowering waste by gathering opinions from respondents. Assessing the perceived significance of these processes enables stakeholders to evaluate how recycling and retreading impact the tire industry's sustainability targets. Tire recycling and retreading prolong tire lifespans, divert waste from landfills, save raw resources, and decrease energy consumption linked to tire manufacturing. Furthermore, these methods promote a circular economy by reusing materials in the production process, decreasing the industry's need for new resources, and reducing its environmental impact. Promoting tire recycling and retreading as essential parts of sustainable materials management can lead to positive environmental results, improve resource efficiency, and help create a more sustainable future for the tire industry and beyond.

330 responses were received for this question globally, and out of those, 94% of the respondents believed that retreading and recycling can definitely promote sustainability in the tire industry. Figure 22 represents the pie diagram of the responses.

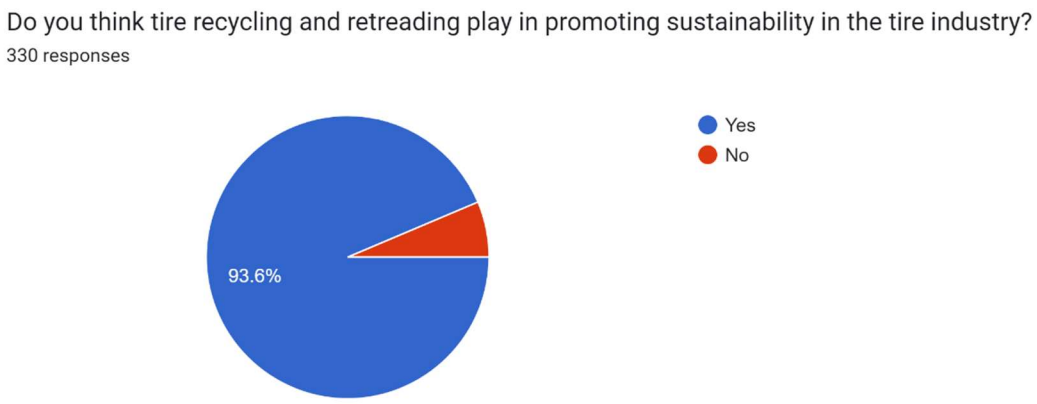


Figure 22: Survey response to question 13, Do you think tire recycling and retreading play in promoting sustainability in the tire industry?

4.3.14 Survey Question 14

Do you think 100% implementation of Extended Producer Responsibility (EPR) for tire industry can be done by 2025?

This question is important to evaluate the partner's opinions on the target of achieving complete EPR compliance in the tire industry by 2025. This investigation offers valuable information on the preparedness of the tire sector, obstacles faced, and potential hindrances to complying with EPR requirements. This response aims to assist policymakers and industry leaders in making informed decisions about strategic planning and resource distribution. Comprehending stakeholder perspectives aids in promoting sustainable material management and reducing the environmental footprint of tire manufacturing and ELT handling.

Figure 23 represents a pie diagram of the responses received globally, which indicates that 67% of respondents believed that the target of 100% implementation of EPR is not a realistic target. However, 33% of respondents believed that it is possible to implement EPR 100% by 2025.

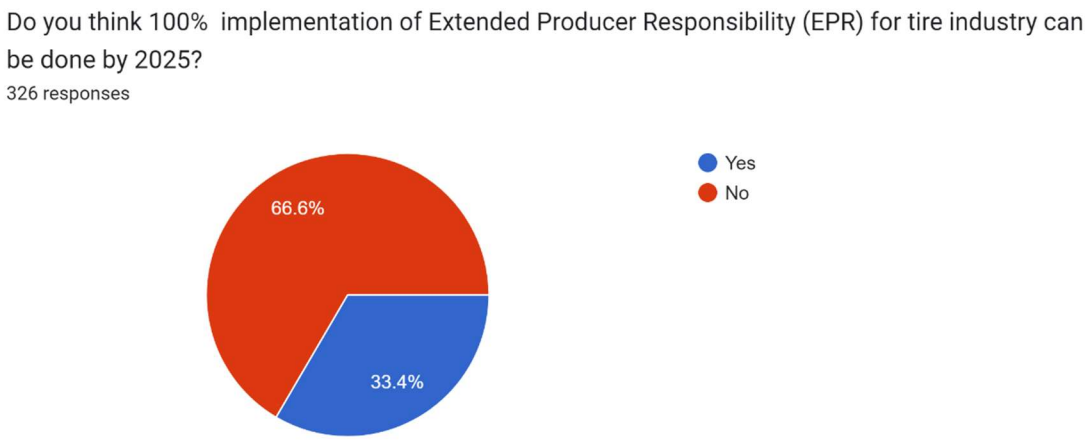


Figure 23: Survey response to question 14, Do you think 100% implementation of Extended Producer Responsibility (EPR) for the tire industry can be done by 2025?

4.3.15 Survey Question 15

How do you think the adoption of sustainable materials will impact the future of the tire industry?

This question is really important for assessing the partner's views on the revolutionary ability of sustainable materials in the tire industry. Their responses provide essential insights on expected changes in industry dynamics, technological advancements, and regulatory environments. Comprehending various viewpoints assists industry

stakeholders in predicting future trends, developing sustainable practices, and adjusting corporate strategies to meet evolving market demands. This inquiry provides insight to policymakers, academics, and investors into the impact of adopting sustainable materials on promoting environmental sustainability and stimulating economic growth in the tire industry.

Figure 24 represents the pie diagram of the responses received globally. 80% of the respondents believed that the adoption of sustainable materials would have a high impact on the future of the tire industry. 16% of respondents believed that sustainable material implementation had a low impact on the future of the tire industry. Only 4% of the respondents believed that there was no impact.

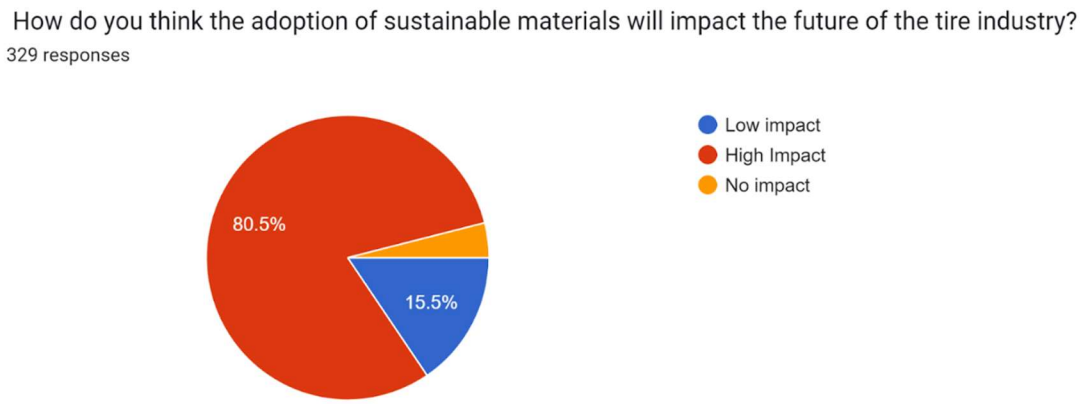


Figure 24: Survey response to question 15, How do you think the adoption of sustainable materials will impact the future of the tire industry?

4.3.16 Survey Question 16

What steps do you think tire manufacturers can take to increase transparency in their sustainability practices?

This question is vital for understanding all related partner's viewpoints on improving openness in the tire industry. Their feedback provides important insights on methods and activities that tire manufacturers might adopt to enhance transparency in their sustainable initiatives. Stakeholders enhance responsibility, trust, and credibility in the sector by pinpointing areas for improvement and proposing real solutions. Addressing transparency concerns fosters better relationships with consumers, investors, and regulatory entities, leading to beneficial changes in sustainable practices in the tire manufacturing industry.

A total of 330 responses were received for this question; out of those, 72% are in agreement with the concept of labelling or engraving on the tire sidewall, whereas 57% of the respondents believed that advertising can increase the transparency of the tire industry's sustainable practices. 42% of respondents were in favour of labelling, on top of the packaging. Figure 25 shows the graphical representation of the responses globally.

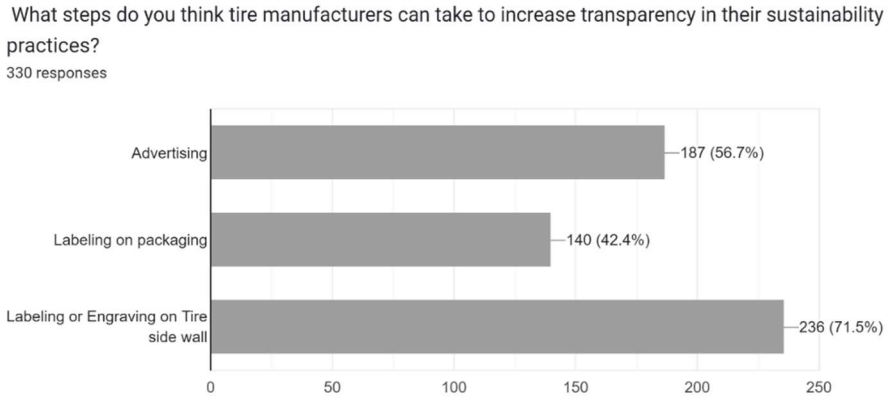


Figure 25: Survey response to question 16, What steps do you think tire manufacturers can take to increase transparency in their sustainability practices?

4.3.17 Survey Question 17

In your opinion, what is the main barrier to the adoption of sustainable materials in the tire industry?

This survey question attempts to identify the main barrier preventing the widespread use of sustainable materials in the tire business. Comprehending these obstacles is essential for creating successful tactics to address issues and expedite the incorporation of environmentally friendly components. Insights from respondents reveal the factors, including cost limits, technological limitations, regulatory impediments, and market demand dynamics, that could hinder the shift to sustainable practices. Identifying the primary obstacle allows stakeholders to create specific solutions and projects to tackle these difficulties, promoting a more sustainable and environmentally conscious tire industry.

A total of 329 responses were received for this question, and out of those, 83% of respondents believed that the availability of raw materials along with the premium cost of sustainable materials were the primary barriers to sustainable material adoption in the tire industry. The rest of the respondents believed that a lack of initiatives from governments was also a hindrance to the implementation of sustainable materials. Figure 26 shows the graphical representation of the responses.

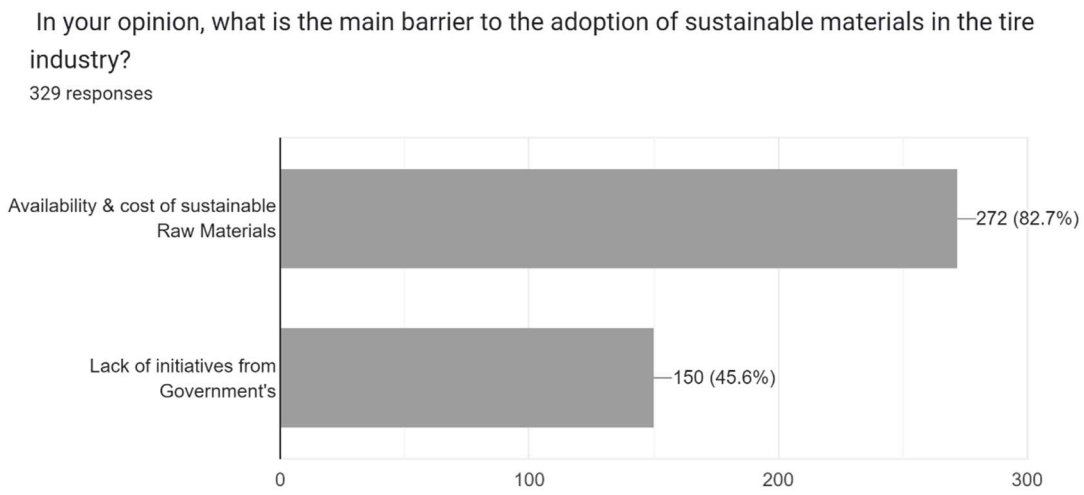


Figure 26: Survey response to question 17, In your opinion, what is the main barrier to the adoption of sustainable materials in the tire industry?

4.3.18 Survey Question 18

How would you rate the level of awareness of sustainable materials in the tire industry in Asian markets on a rating scale of 1 to 10?

The researcher employed a 1–10 rating scale, which enables respondents to provide a numerical assessment of their perception, providing significant insights into the level of awareness among industry stakeholders. Any rating close to 10 signifies a strong level of awareness among tire producers, suppliers, policymakers, and consumers regarding sustainable materials and their advantages. A lower ranking indicates a requirement for increased awareness campaigns and educational initiatives to encourage the implementation of sustainable practices. This helped the researcher assess the efficiency of current awareness initiatives.

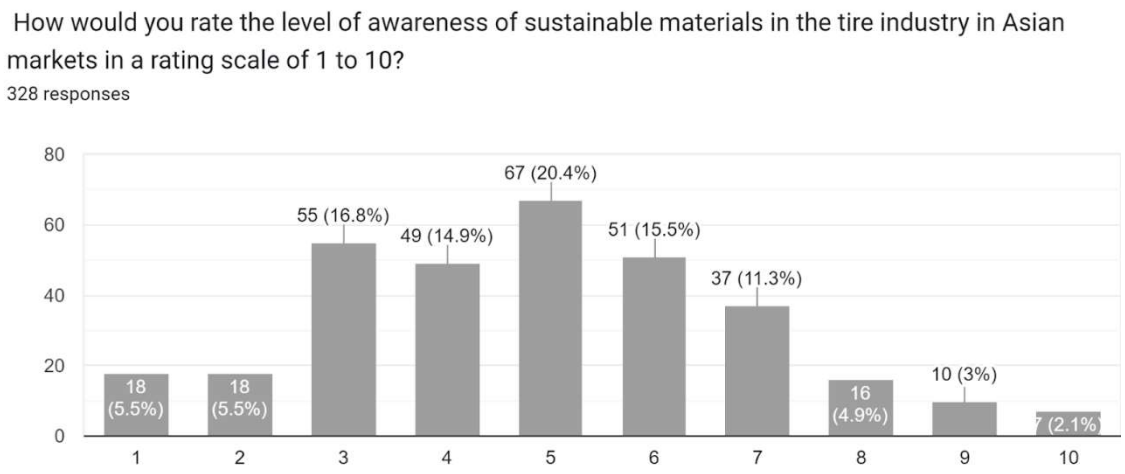


Figure 27: Survey response to question 18, How would you rate the level of awareness of sustainable materials in the tire industry in Asian markets in a rating scale of 1 to 10?

A total of 328 responses were received for this question, and the overall curve is towards the lower side of the scale. This indicates that the awareness of the Asian tire industry requires lots of awareness programs on the sustainability front. Figure 27 provides a graphical representation of the responses received.

4.3.19 Survey Question 19

How would you rate the level of awareness of sustainable materials in the tire industry in European markets on a rating scale of 1 to 10?

The researcher employed a similar scale and technique as in the previous question in this case. This question was really important to identify the awareness of the European market towards sustainable material implementation. Figure 28 provides a graphical representation of the responses received. The graph is aligning towards the higher side of

the scale, indicating a higher awareness of European markets for sustainable materials and practices.

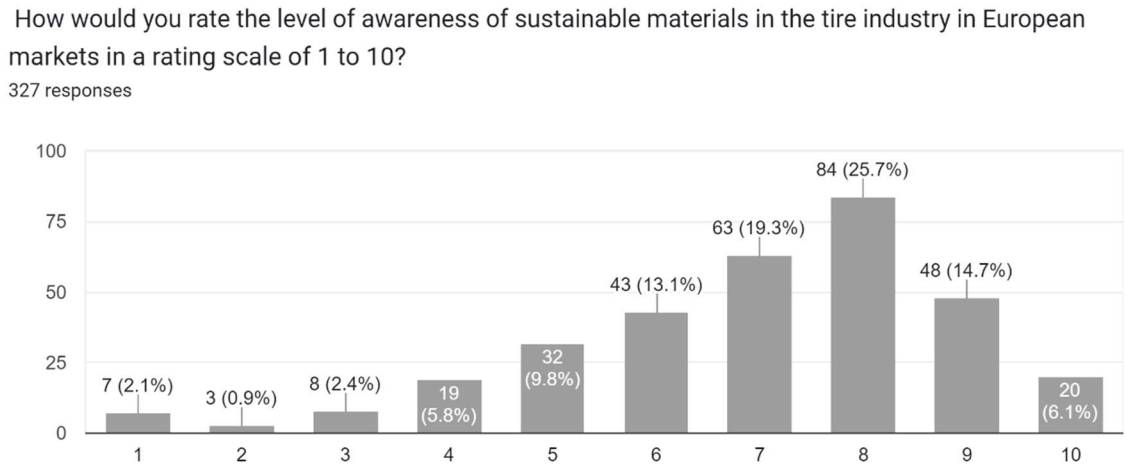


Figure 28: Survey response to question 19, How would you rate the level of awareness of sustainable materials in the tire industry in European markets in a rating scale of 1 to 10?

Figure 28 provides a graphical representation of the responses received. The graph is aligning towards the higher side of the scale, indicating the higher awareness of European markets for sustainable materials and practices.

4.3.20 Survey Question 20

Can you tell us about the identity as an industry person or an end user?

This question was intended to bifurcate the received data based on the industry. This could provide a clear picture of the people's perspective about the above 19 questions and help the researcher analyze both the geography of Asia and Europe in terms of

sustainability initiatives, awareness and customer willingness to buy sustainable tires at a premium cost.

The researcher received a good combination of responses from industries. 51% of the respondents are from the tire industry, 22% are end users, and 13% each are from non-tire and raw material manufacturers. Figure 29 represents the pie chart of the responses receive globally.

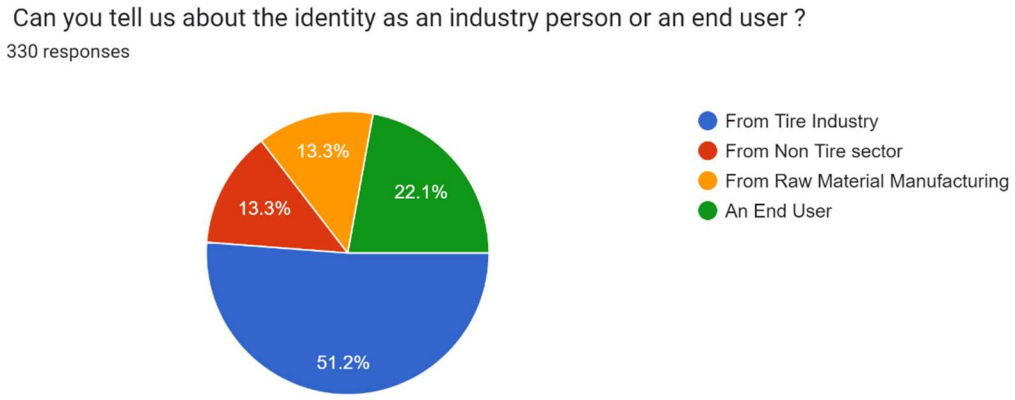


Figure 29: Survey response to question 20, About the identity of the respondent as Tire, no tire, raw material and end user.

4.4 Summary of Findings

Based on the detailed analysis of direct interviews of 15 experts globally, review of sustainable materials and process related patents with the help of WIPO Patentscope, in depth analysis of sustainability reports from global tire manufacturers and the global survey results on sustainability conducted by the researcher, the following are the major findings;

The direct interview of experts from tire and allied industries provides an idea about the importance of the government's policies on promoting sustainable materials in the tire

industry. The majority of the interviewee, irrespective of their geographical location, agree that the government's policies are playing an important role in promoting sustainable materials and practices in the tire industry.

The interviewees also discussed the challenges needed to overcome for the incorporation of sustainable materials in the tire without affecting the performance and durability of the tire. All these factors must be considered, keeping in mind the cost of the tires, which is an important influence on the buying decision. The primary challenge pointed out by the interviewees was the extensive amount of research and validation required for incorporating any material in the tire, as the impact of any change can be huge on tire performance. Detailed studies are required in order to tackle these challenges, and industrialization and adequate material availability for the tire industry are the most important things. Many of the sustainable concepts are still in the research stage, with researchers going in the direction of improving tire performance and characteristics through the use of sustainable materials, through special treatments and surface modifications. In a nutshell, the quality and availability of sustainable materials at a considerable cost are the major challenges that industries need to overcome to implement efficient usage of sustainable materials.

Furthermore, the impact of sustainable materials on the overall carbon footprint of the transportation sector was discussed. The outcome was that there is an impact, but it can be roughly ~6% of the total contribution of tires, considering the share of tires in the total sector, which is considered ~20%. The major contributors are the maritime and aviation segments; road transportation contributes about 20%, of which 80% is from the combustion

of the fuel and the remaining 20% can be from tires. Hence, the impact on the overall carbon footprint of the transportation sector is minimal due to the sustainable material incorporation in tires; however, considering the standalone contribution of tires, the impact of the incorporation of sustainable materials in tires is significant.

The researcher received information about the extensive research that tire and related manufacturers needed to conduct in order to meet the safety and performance requirements of tires when incorporating sustainable materials into the tire from the experts. Many quality improvements are required for recycled and derived materials, which require collaborative initiatives between recyclers, raw material manufacturers, and government bodies promoting sustainable initiatives. This provides a pathway to the direction of potential avenues of technological advancement by tire companies as well as recyclers and raw material manufacturers. Also, the experts highlighted the importance of securing the intellectual property rights (IPR) of these inventions.

The researcher received valuable information about transparency in sustainable development and communications by directly interviewing the experts. Tire manufacturers can enhance transparency in their sustainable practices, build consumer trust, and drive positive industry change by implementing a comprehensive strategy that includes stakeholder engagement, certification and verification, honest openness, and efficient communication. In addition, the interviewees expressed their view that the European region is leading sustainability initiatives, whereas the Asian region is catching up at a fast pace.

From the patent review, it is clear that Asian inventors are leading the innovation space, irrespective of the sustainable maturity of the European region. However, both Asia

and Europe regions are contributing towards innovation. Another important finding from the data analysis is that the contribution from the tire manufacturing sector towards innovation is really strong.

Based on the sustainability report review of tire companies globally, the tire industry, irrespective of the region, follows United Nations Sustainable Development Goals (SDGs) as the guideline for drafting sustainability norms and policies. Tire companies are incorporating this into their core purpose. Tire industries from European regions are clearly mentioning the target value and deadline for initiative on norms like carbon neutrality and zero emissions, on the other hand, a few tire companies from Asian countries are able to provide the clarity, even though they are trying to incorporate it into their sustainability reports.

The researcher received valuable feedback from the survey participants globally. The participants were primarily from tire manufacturing, and the data was authenticated considering their deep expertise. Also, the findings were substantiated by the views of non-tire, raw material, and end users in addition to the participants from tire industries. The survey provided a detailed understanding of the current state of sustainability initiatives and awareness among European and Asian regions. On the sustainability front, Europe is the pioneer, whereas the Asian region is the follower, even though they lead the innovation regime.

4.5 Conclusion

In conclusion, the researcher was able to acquire significant material to address the research question by conducting direct interviews, searching for patents, analysing the

sustainability report of a tire manufacturer, and conducting a survey among participants located all over the world. Although there was a variation in the percentage of participants, the bulk of those who took part in the interview were from Asian regions. The interview was conducted with experts from both Asia and Europe. In a similar fashion, the bulk of the people who participated in the interview were from Asian countries, despite the fact that European regions had a satisfactory level of involvement. When it came to the evaluation of the patent and sustainability report, the researcher did not encounter any particular concerns as the data was available in the public domain.

CHAPTER V:

DISCUSSION

5.1 Discussion of Interview Results

The researcher conducted the interviews on a global basis, with a special emphasis placed on the regions of Asia and Europe. This was done in light of the immense magnitude of the tire sector. These interviews were conducted with the intention of gathering qualitative data concerning the usage of sustainable resources and the methods that are implemented by tire companies, as well as the industries that are associated with them, to answer the research questions. The following are the research questions;

5.1.1 Research Question 1

What are the disparities in sustainability initiatives and the adoption of sustainable materials in the tire industry between the Asian and European regions?

5.1.2 Research Question 2

What factors promote and impede the adoption of sustainable materials in these markets?

It was taken into consideration the level of knowledge and expertise of the individuals being interviewed when it came to the selection process of interviewees. Many of the interviewees were in senior leadership positions, and a few were directors. The

researcher approached each question with the objective of answering the research questions.

5.1.3 Interview Question 01

To what extend do government policies contribute to the promotion of sustainable materials in the tire sector?

Based on the 15 expert responses to this question, the researcher was able to convert them to answer the research questions. The responses shed insight on the varied positive effects that government policies have on the tire sector in terms of supporting the adoption of techniques and materials that are sustainable. The preliminary frameworks that support sustainable growth are regulatory frameworks, incentive programs, certification systems, and third-party re-validation systems. Numerous interviewees emphasised this fact, which assisted the researcher in identifying the disparities in both Asian and European regions as well as the factors that are promoting and impeding the incorporation of sustainable materials in the tire industry.

In addition, the attainment of sustainable development goals is contingent upon the collaboration of recyclers, manufacturers of raw materials, and manufacturers of tires, all of whom work together with governments. There is a consensus among specialists from both the European and Asian regions that the degree of awareness is lower in the Asian region in comparison to the European region. However, as a consequence of steps taken by Asian governments and tire companies, the gap that exists between these regions is beginning to diminish.

5.1.4 Interview Question 02

What are the key challenges that tire producers need to overcome in order to incorporate sustainable materials?

The researcher gathered information to answer the research questions from the expert's opinions. As industry experts say, during the early phases of adoption, the abundant availability of sustainable materials is a major challenge. This is because many of the recyclers, or sustainable material manufacturers, are start-ups at a very young stage of technical and supply chain maturity. They are facing challenges in acquiring reliable sources of raw materials for them, as well as process variations in their operations. Integrating these new materials into tire design and production processes requires significant trial and error methods, and this is another challenge for tire manufacturers in developing suitable technology to suit the product requirements. These projects necessitate substantial investments in research and development, along with technological improvements. This can be accomplished by engaging in a collaborative development process with recyclers and raw material manufacturers to ensure compliance with the relevant quality requirements. In addition to the above, the experts mentioned the technological and infrastructural advancements in the European region in comparison with Asis, enabling them to lead the sustainability regime. This fact made European customers aware of sustainability initiatives, and they are ready to pay a premium for products that are sustainable.

In conclusion, availability, cost, technology, and extensive research required to match the performance and safety parameters while using sustainable materials are the major challenges. The response to this query provided the factors promoting and hindering the implementation of sustainable technologies and materials, in addition to the disparities between Asia and Europe

5.1.5 Interview Question 03

How does the utilization of sustainable materials by the tire industry impact the overall carbon footprint of the transportation sector, and to what extend?

The researcher draws the conclusion that sustainable material usage in tires has a minimal impact on the total transportation sector's carbon footprint. Around 6% of the entire contribution comes from tires, based on tires' share of around 20% in the total contribution of the road transportation sector. The primary contributors are the maritime and aviation sectors, which make up around 80%. Road transportation accounts for around 20% of the total emissions, out of which 80% comes from the combustion of fossil fuels and the remaining 20% from tires. However, the incorporation of sustainable materials in tires has a considerable impact on their standalone carbon footprint.

5.1.6 Interview Question 04

How do tire producers find a balance between using sustainable materials and complying with safety and performance regulations?

The expert's opinion provided valuable information for the researcher to conclude on the safety and performance of tires while using sustainable materials. At present, the available sustainable materials are not able to provide superior quality when compared to virgin materials. However, there are a few materials that are extremely good in quality; those are recycled and treated specially to retain and enhance the quality parameters, and these materials have a premium cost. All the interviewees agreed that extensive research is required to maintain both safety and performance in tires made with sustainable materials.

In conclusion, tire manufacturers focus on finding the best combination of materials and manufacturing methods to enhance product efficiency while reducing environmental impact. Progress in recycling old tires, such as producing high-quality reclaimed rubber crumbs and activated crumbs, offers improved ways to maintain safety and performance criteria. Tire manufacturers need to embrace innovation, collaboration with recyclers, raw material manufacturers, and strategic planning to find a balance between sustainability and adherence to regulations in tire production.

5.1.7 Interview Question 05

What are the potential avenues for technological advancements and innovations in the use of sustainable materials within the tire industry?

The researcher synthesised the information received during the interview to draw conclusions on the potential avenues for technological advancement and innovation. This helped the researcher identify the factors that can support the implementation of sustainable materials in tire manufacturing. Many specialty treatments and materials were discussed

by the experts during the interviews, those include polymers, fibres, fillers, and bio-derived resins. In addition to that, process modification can process the recycled materials much more effectively with minimal deterioration in quality parameters. Surface treatments of modified rubber crumbs may retain the quality parameters at par with the virgin rubbers that can be effectively used in tires without performance and safety compromises.

In conclusion, there is an arena opened for technological advancements and innovations, which are not limited to material and processing, but to product design also. All the respondents pointed out regarding securing the intellectual property rights (IPR) of the innovation

5.1.8 Interview Question 06

What measures can tire manufacturers adopt to enhance transparency in their sustainable practices?

To come to a conclusion about improving the transparency of the sustainable initiatives and practices used by tire manufacturers, the researcher compiled the data provided by the experts. The tire manufacturers can enhance transparency in their sustainable practices, which can build consumer trust and drive positive industry change through a comprehensive strategy that includes stakeholder engagement, accreditation and verification, transparent disclosure, and effective communication. Organisations can communicate their sustainability initiatives and include stakeholders in discussions about sustainability and social responsibility by using proactive communication methods such as advertising campaigns and public outreach.

In the European region, tire companies are already coming up with innovative ways of engraving sustainable material usage logos on the tire sidewall. Considering its significance, the researcher initially discussed this and included it in the survey questionnaire.

In conclusion, practices of effective stakeholder engagement, accreditation and re-verification from third parties, transparent disclosure of sustainable developments, and effective communication with customers can enhance transparency for the general public

5.1.9 Interview Question 07

How do the European and Asian markets compare in terms of the adoption and utilization of sustainable materials in the tire sector?

The researcher gathered vital information about the comparison of Asian and European regions in the adoption and usage of sustainable materials through direct interviews. This helped in identifying the disparities between these regions. Based on the 15 expert opinions, the researcher could conclude that Europe is at the forefront of sustainability adoption and awareness, while Asian markets are rapidly progressing due to an increasing recognition of the importance of green practices and the need to adhere to global standards.

Asian tire manufacturers are adopting sustainable technology and practices with the help of regulations and international partnerships, aiming to compete with European markets and establish a strong presence in the global sustainable tire industry. European

and Asian tire makers must focus on developing, collaborating, and investing in sustainable technology to stay competitive in a rapidly changing business. The tire industry can advance towards a more sustainable and resilient future by leveraging the resources of each location and addressing the challenges of implementing sustainable material usage and practices.

5.2 Discussion of Patents Search Results

As part of the study, the researcher conducted a patent search using the WIPO Patentscope database to investigate the most recent advancements and trends in sustainable materials in the tire industry. The search was focused on 23 particular keywords, which are given in Table 2 in the results. For comparison, 26 countries from Asia and 25 countries from Europe are considered.

The summary of the search results showed that Asian countries are leading the innovation space, even though European countries are leading sustainability initiatives and awareness.

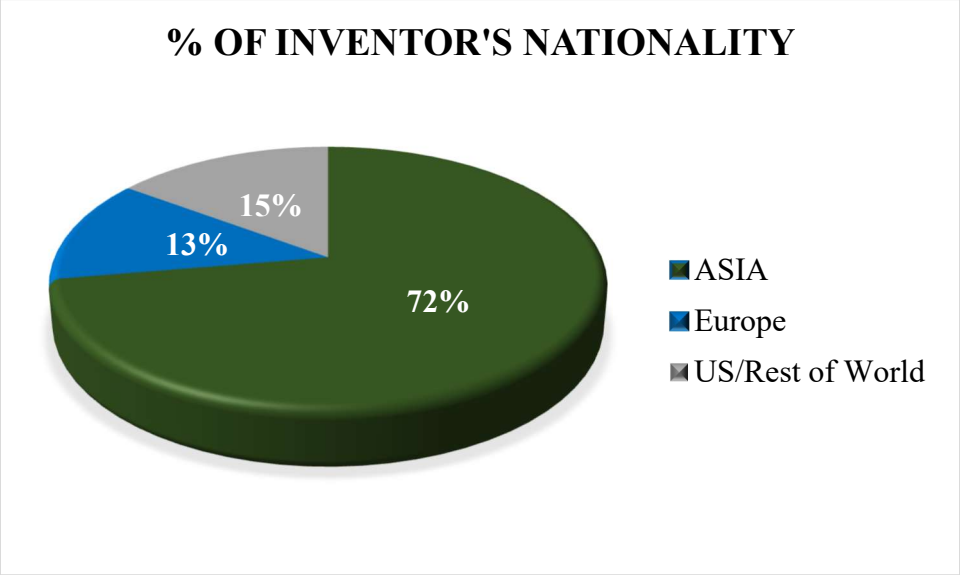


Figure 36: Patent Search Results

This above Figure 36 shows the percentage distribution of the innovators' countries. The detailed analysis indicated that about 25% of these patents are from the tire industry, which shows the seriousness of the industry towards sustainability. These higher percentages of innovations in Asian countries are helping them catch up with the pace of sustainability in Europe. This information substantiates that innovations are seriously promoting the sustainability movement.

5.3 Discussion of Sustainability Report Results

The researcher conducted a detailed examination of sustainability reports from tire industries in Asia and Europe to provide insights into their commitment to environmental stewardship, social responsibility, and economic sustainability. Tire industry leaders such as Continental AG, Michelin, Goodyear, Bridgestone, MRF, CEAT, Yokohama, BKT, JK, and Apollo Tires were included in the sustainability report assessment. The selection of

these companies ensured global representation, even though the major focus was on Asia and Europe.

Based on the review, the researcher concluded that tire firms worldwide are adhering to the United Nations 17 Sustainable Development Goals when formulating their sustainable objectives (United Nations, 2015). All the regions included GHG emission standards, carbon neutrality target values and deadlines, an attitude towards the circular economy, the value chain, good working conditions in green factories, and sustainable management practices.

Figure 37: Michelin - Sustainability performances (Source: Michelin, 2023)

Figure 37 indicates the incorporation of the UN's SDGs into Michelin's sustainability targets and the actions and approach towards the cause. Similarly, many of the major tire manufacturers are included in the UN's directives on sustainability actions as well as the report. Figure 38 shows the incorporation of the circular economy into the integrated sustainability report of Continental AG.

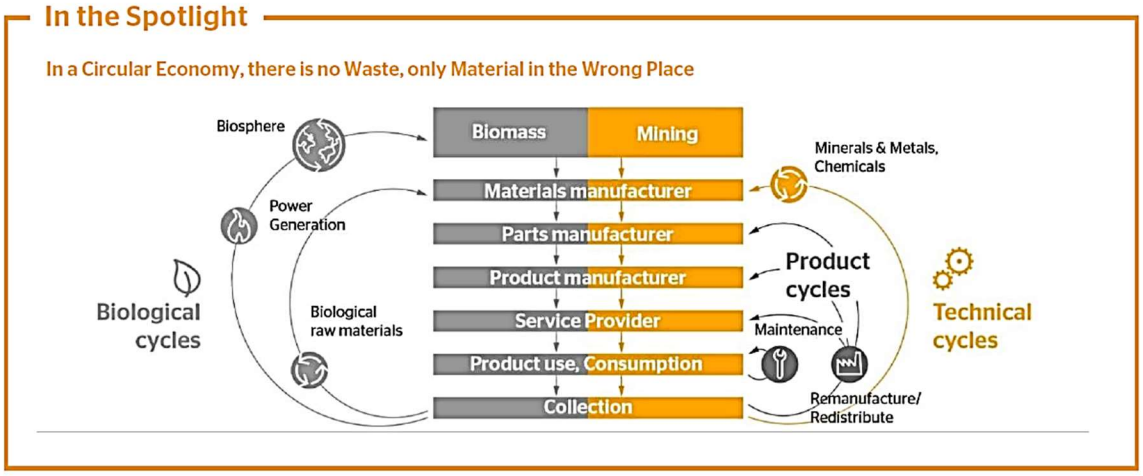


Figure 38: Integrated Sustainability Report 2022 (Source: Continental AG, 2022)

Megatrend*	Impact on the Sector*	Relevant SDGs Goodyear is Supporting
Circular innovation to tackle resource scarcity	Burgeoning populations in emerging markets and increased urbanization globally are encouraging a rise in mobility. The resource challenges that can result from growing demand present the opportunity for the emergence of new business models such as those based on the circular economy.	
Climate and nature crises to accelerate the low-carbon energy transition	Progress to reduce greenhouse gas (GHG) emissions, adapting to the physical impacts of climate change and halting biodiversity loss remains slow and insufficient. However, new regulations, investor pressure and citizen power have created momentum to which the business community must respond.	
Industry 4.0 to allow systems transformation	Rapid digitalization and automation across industries is driving improved productivity, efficiency and safety—but could lead to widespread and disruptive implications for employment and workforce skills if not appropriately managed. Technologies, including artificial intelligence, internet of things and 5G, alongside autonomous, connected and electric vehicles, offer significant opportunities to organizations ready to embrace them. The adoption of such technologies must come with efforts to address rising cybersecurity and data privacy concerns and to manage the potential environmental impacts from material and energy consumption.	
Human rights, safety, well-being and equal opportunities – across the value chain – are essential to building resilience.	Rising inequality is driving continued dissatisfaction with current political and economic models and global civil protests on issues relating to diversity and inclusion. Companies are increasingly expected to take strong positions on human rights and other social issues – including protecting employee well-being, promoting workplace safety and improving supply chain due diligence and transparency – to ensure long-term business resilience.	

Figure 39: Corporate Responsibility Report 2022 (Source: Goodyear, 2022)

On analysing the sustainability reports of Asian and European tie manufacturers, it shows that they are serious about the UNs sustainable development goals (SDGs). In conclusion, while Asian tire manufacturers have addressed some UN Sustainable Development Goals in their sustainability reports, there is room for improvements to match the sustainability reporting standards and practices seen in Europe and other regions. The company's ambitious goals for initiatives such as achieving carbon neutrality and zero emissions within a specific time frame build confidence in sustainability among customers

and stakeholders. The researcher underscores the importance of tire companies following the UN's Sustainable Development Goals (SDGs). The analysis points to the disparities in practices followed in both Asian and European regions, which the research question was intended to answer by the researcher.

5.4 Discussion of Survey Results

5.4.1 Survey Question 1

Country you are residing?

The researcher collected 327 answers worldwide using Google Forms. Figure 40 displays the colour intensity-based representation of representation globally. This indicates the respondents' presence was global, irrespective of the number of participants. This helped the researcher provide reliability and validity to the data.

The majority of the respondents were from India (78%), and a total of 84% of responses were received from Asia and 13% from Europe. Figure 41 shows the country wise % response and Figure 42 shows the pie chart of region wise participants percentage.

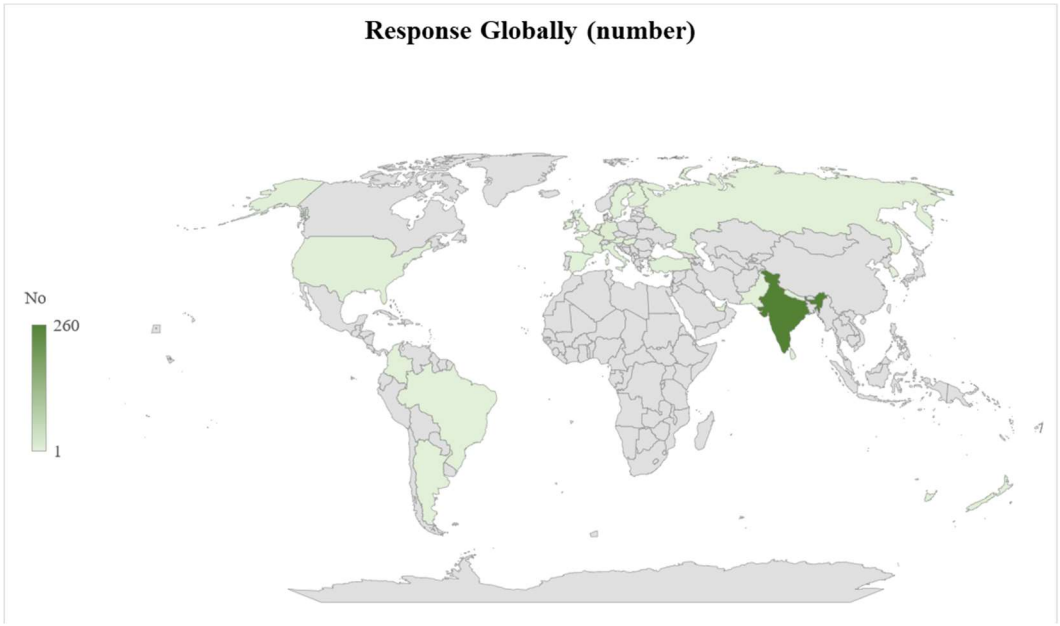


Figure 40: Global map with colour intensity-based number of respondents

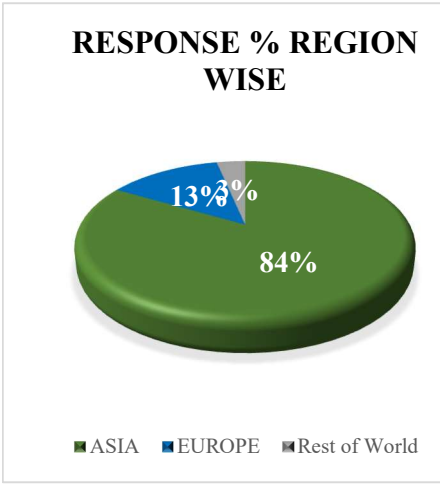


Figure 41: Country wise response to survey question 01

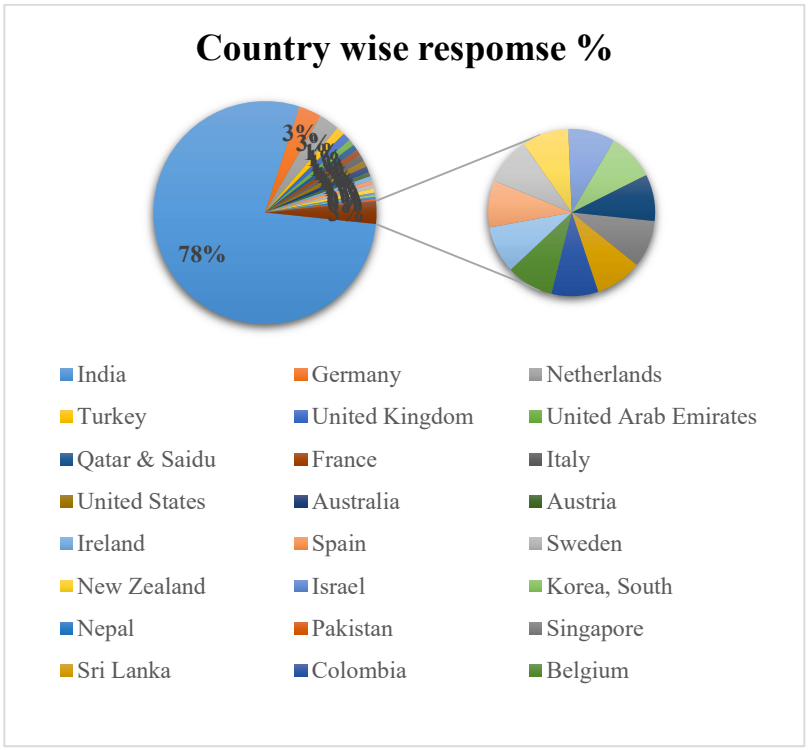


Figure 42: Region wise response to survey question 01.

Tables 06 and 07 provide the count and percentage of responses. The above information helped the researcher conclude the other questions much more effectively. This information was a crucial data point for the researcher in stratifying the remaining queries in an effective way. Here, the researcher dives into the details of global, region, and country wise classification of the received data.

List Asian Countries	**No of Responses**	**%**
India	260	78
United Arab Emirates	3	1
Turkey	4	1
Israel	1	0.3
Korea, South	1	0.3
Nepal	1	0.3
Pakistan	1	0.3
Qatar & Saudi	3	0.9
Singapore	1	0.3
Sri Lanka	1	0.3
Colombia	1	0.3
Total	**277**	**83.4**

Table 06: List Asian Countries response to question 01

List of EU Countries	**No of Responses**	**%**
Germany	11	3
Netherlands	10	3
United Kingdom	4	1
France	3	1
Italy	3	1
Austria	2	1
Ireland	2	1
Spain	2	1
Sweden	2	1
Belgium	1	0.3
Finland	1	0.3
Hungary	1	0.3
Russia	1	0.3
Slovakia	1	0.3
Total	**44**	**13.3**

Table 07: List European Countries response to question 01

5.4.1 Survey Question 2

Do you think sustainable materials will become the norm in the tire industry in the future?

Figure 43 represents the pie diagram of global responses; in Figure 44, the response from the Asian region is captured, and in Figure 45, Europe's response is captured against this question. A total of 332 responses were collected globally for this question. Figure 46 shows a consolidated idea of responses region wise. Approximately 96% of respondents worldwide believe that sustainable materials will become standard in the tire business in the future, while only 4% think it may not become the norm in the future. This data helped the researcher to substantiate research question two, as government norms can push sustainable material incorporations in the tire industry

Figure 43: Global response to survey question 02.

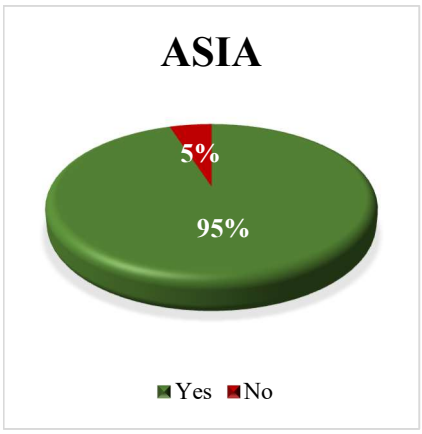
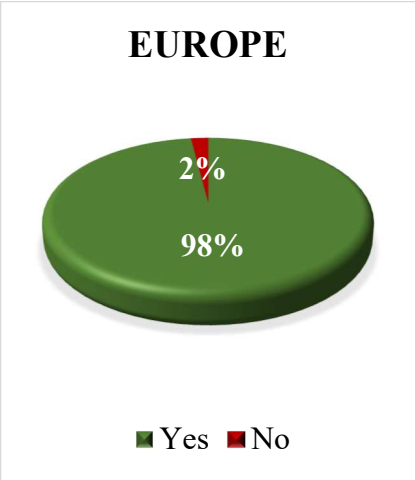


Figure 44: Asia's response to survey question 02



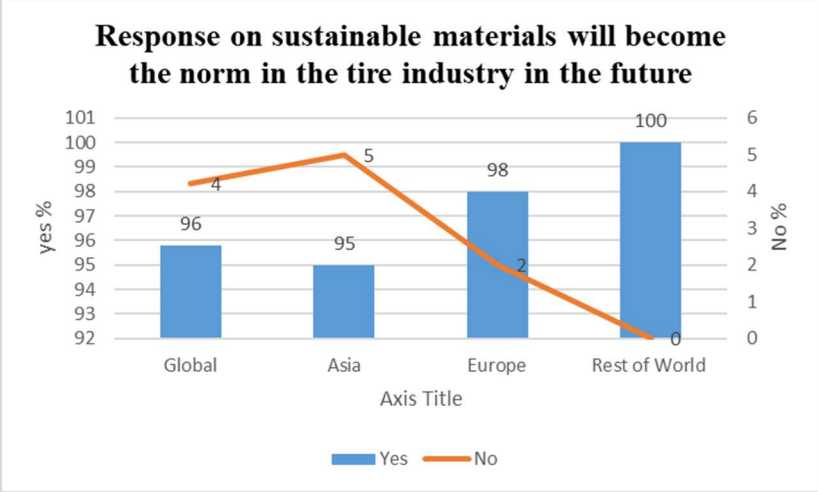


Figure 45: Europe's response to survey question 02

Figure 46: Total region wise response to survey question 02

5.4.3 Survey Question 3

Which tire market is leading the adoption of sustainable material usage?

Figures 47–51 give a detailed idea of the market that is leading sustainable material usage. Tables 08 and 09 give clarity on industry wise responses from Asia and Europe. A total of 329 responses were received globally, and out of those, 73% of the respondents agreed that Europe is leading the adoption of sustainable materials and practices, whereas 27% believed that Asian countries are leading sustainable material usage and practices. The researcher further sliced the data region wise to get a feel, 70% from Asia and 93% from Europe believed Europe was leading the sustainability move. This helped the researcher identify the disparities in both regions, ultimately addressing the research questions.

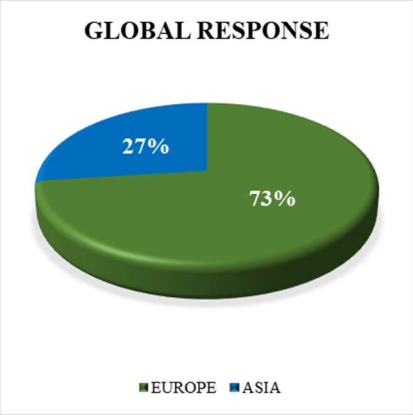


Figure 47: Global response to survey question 03

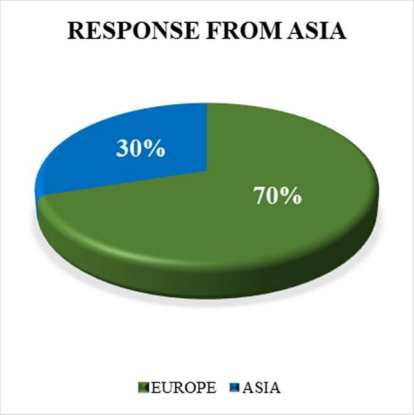


Figure 48: Response from Asia to survey question 03

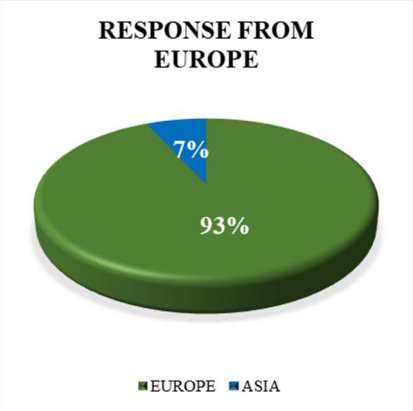


Figure 49: Response from Europe to survey question 03

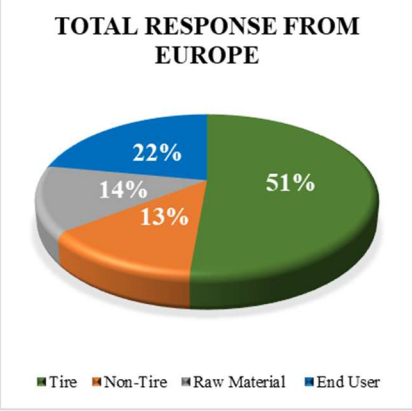


Figure 50: Industry wise Response from Europe to survey question 03

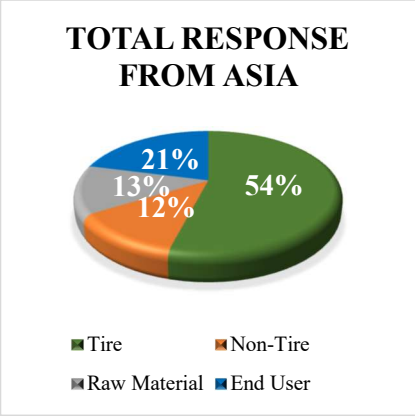


Figure 51: Industry wise Response from Asia to survey question 03

	Europe	Asia	Global
Tire	53.8	44.8	51.4
Non-Tire	10.0	21.8	13.1
Raw Material	13.3	13.8	13.5
End User	22.9	19.5	22.0

Table 08: Industry wise % of response to question 03 from Europe

	Europe	Asia	Global
Tire	57.1	46.9	54.0
Non-Tire	8.9	19.8	12.1
Raw Material	12.6	13.6	12.9
End User	21.5	19.8	21.0

Table 09: Industry wise % of response to question 03 from Asia

5.4.4 Survey Question 4

As an end user, are you willing to buy a tire with sustainable materials at a higher cost?

The willingness to buy tires that are sustainable at a higher price is an important aspect, as it is crucial information for the tire industry and its important value chain. The researcher received 332 responses for this question. Despite the researcher's initial assumption that people would not want to buy tires made from sustainable materials at a higher price, 59% of the global respondents indicated their willingness to do so. 41% of respondents were unwilling to buy tires made of sustainable materials at a higher price.

Figures 52-55 provide a graphical representation of the responses, global, Asia, Europe and rest of World respectively. Table 10 gives the region wise response to this question. The answers to this question provided valuable information to the researcher, which can be helpful for tire manufacturers, sellers, and decision-makers to tailor their approaches, goods, and communication techniques to meet consumer preferences for eco-friendly options, taking into account pricing and value propositions. Through the responses to this question, the researcher underlined the disparities and priorities of the Asian and European markets, which the research question was intended to answer.

Figure 52: Global Response to survey question 04

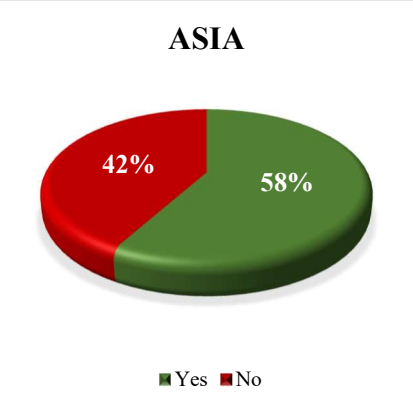


Figure 53: Asia's Response to survey question 04

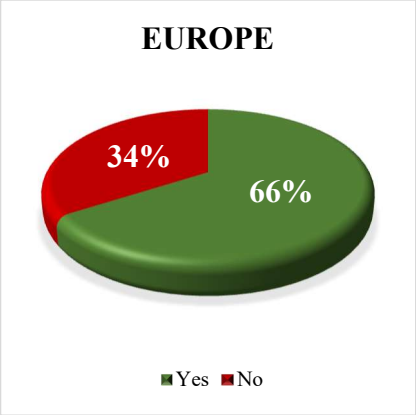


Figure 54: Europe's Response to survey question 04

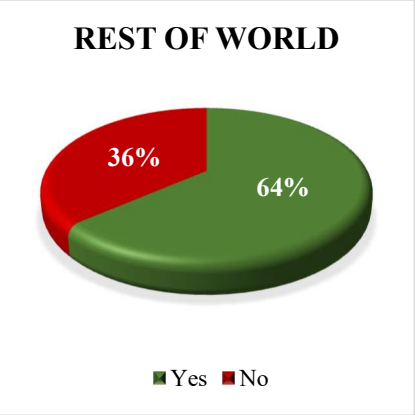


Figure 55: Rest of World's Response to survey question 04

	Global		Asia		Europe		Rest of World	
	Count	%	Count	%	Count	%	Count	%
Yes	197	59.3	161	58.1	29	66	7	63.6
No	135	40.7	116	41.9	15	34	4	36.4
Total	332	100	277	100	44	100	11	100

Table 10: Region wise response to question 04

5.4.5 Survey Question 5

Do you think Asian governments are making policies in promoting sustainable material usage?

The researcher was able to collect 328 responses, out of which 65% of respondents worldwide stated that Asian governments are implementing initiatives to encourage sustainable material usage. 35% of respondents thought that Asian governments were not implementing enough policies to encourage sustainable material usage in the tire business.

Figure 56 gives an idea of the response percentage and count region wise. The researcher incorporated this question into the survey to get the customer's perspective on the legislative strengths on sustainability in both regions to help answer the research questions.

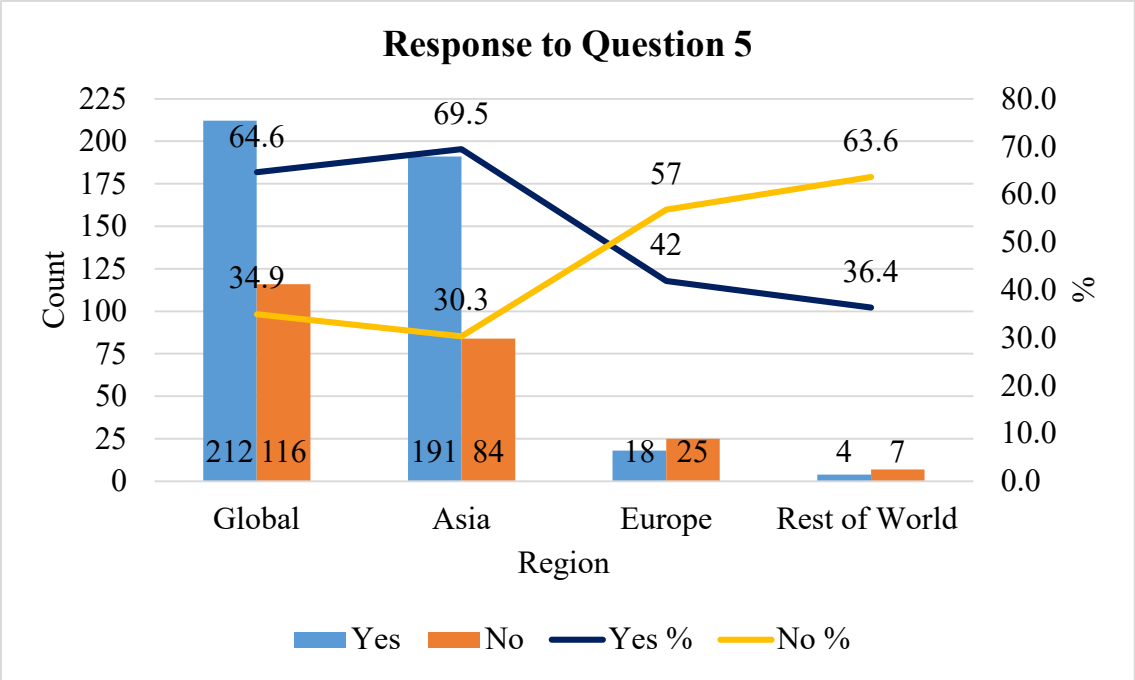


Figure 56: Response to Question 05

5.4.6 Survey Question 6

Do you think the usage of sustainable raw materials can affect the tire performance and quality?

This question was intended to assess the awareness of stakeholders about the effects of sustainable materials on the performance and quality of tires. After receiving 326 responses, the researcher found that 43% of respondents worldwide are unaware of

sustainable material usage and its impact on tire performance and quality. 34% thought sustainable materials would improve tire performance and quality. 23% said sustainable tire materials degraded performance and quality.

Figure 57 shows the graphical representation of the number of responses region wise. Figure 58 gives the response percentage industry wise. Table 11 gives an idea of the industry wise awareness globally in number as well as in percentage. The response to this question provided awareness of the disparity of sustainable materials in both regions. Majority of the stakeholders are unaware of the effect of sustainable materials on tires, irrespective of the industry. This helped the researcher to get the present scenario of awareness of sustainable materials in the tire industry globally.

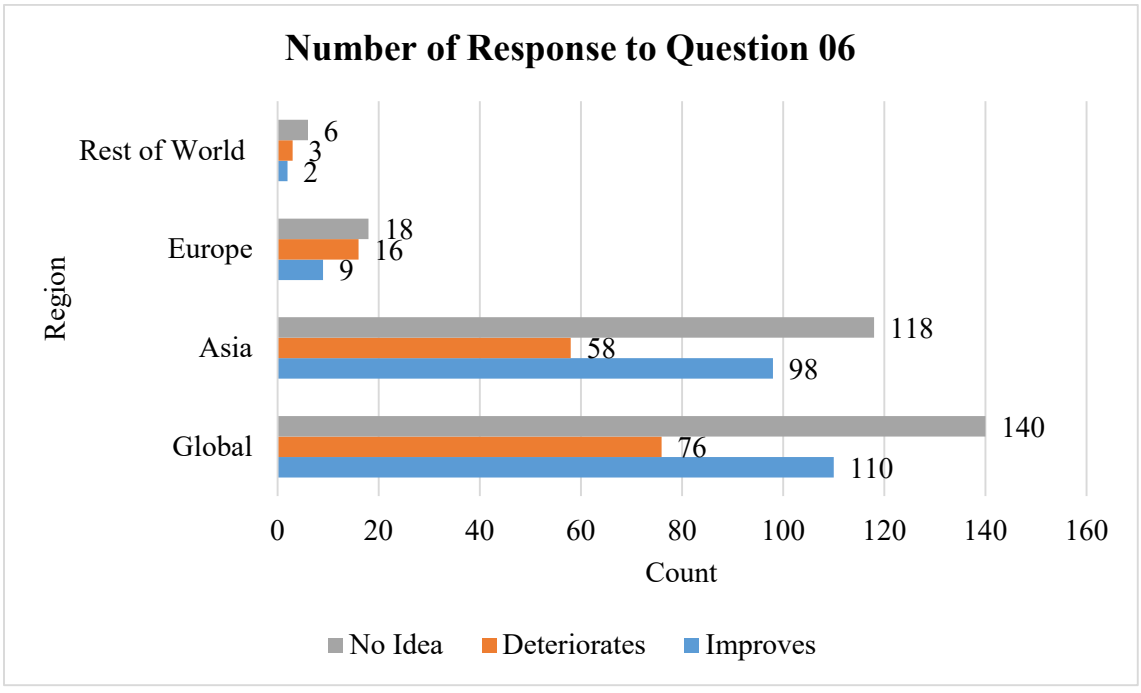


Figure 57: Number of Response to Question 06

	Tire		Non-Tire		RM		End User	
	Count	%	Count	%	Count	%	Count	%
Improves	57	34.1	12	29.3	15	35	25	34.7
Deteriorates	47	28.1	4	9.8	14	33	9	12.5
No Idea	63	37.7	25	61.0	14	33	38	52.8
Total	167	100	41	100.0	43	100	72	100.0

Table 11: Industry wise response to question 06

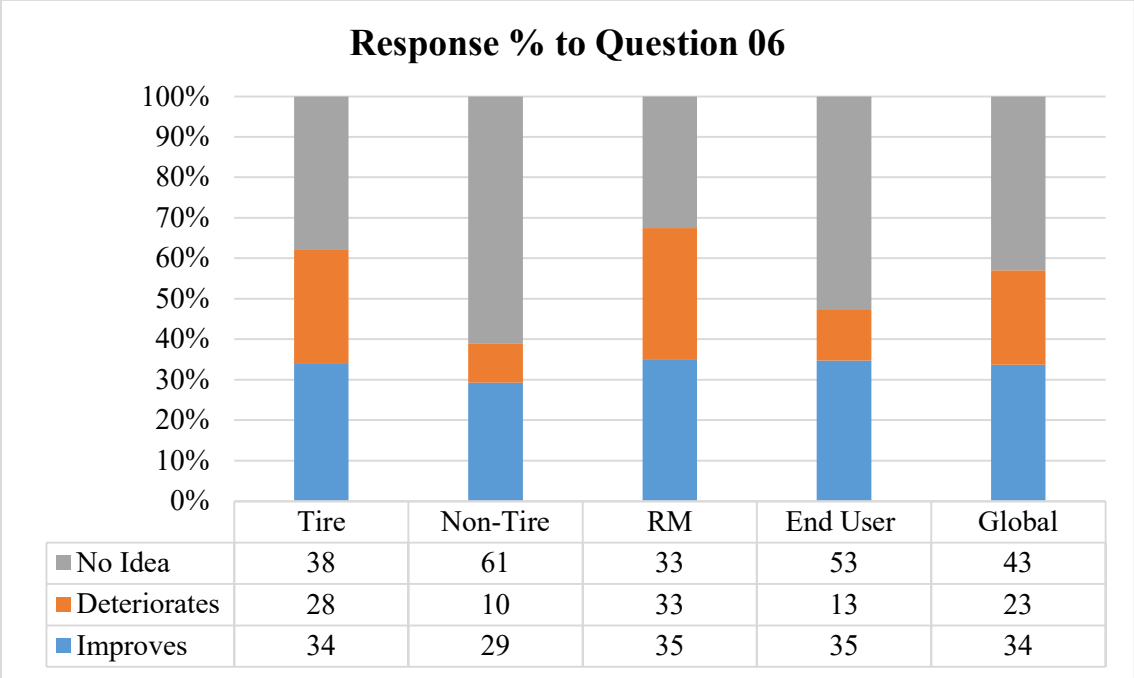


Figure 58: % of Response to Question 06 Industry wise

5.4.7 Survey Question 7

Do you think tire producers can ensure the tires made from sustainable materials will have both durability and excellent performance?

Tables 12-15 give an idea of the tire manufacturer's capability to make tires with sustainable materials, ensuring both durability and excellent performance. Responses were

categorised region wise, globally, by Asian region, and by European region. This helped the researcher synthesise the data effectively.

The results revealed that globally, 72% of respondents are confident in the capability of tire manufacturing to use sustainable materials and maintain durability and performance. This confidence level in Europe was on the higher side, and this could be due to the better awareness about sustainable materials in this region. Through this question, the researcher gathered the region wise awareness and confidence of stakeholders.

	Global		Asia		Europe		Rest of World	
	Count	%	Count	%	Count	%	Count	%
Yes	237	71.8	191	69.5	38	86	8	72.7
No	18	5.5	18	6.5	0	0	0	0.0
Don't Know	75	22.7	66	24.0	6	14	3	27.3
Total	330	100	275	100.0	44	100	11	100.0

Table 12: Region wise response to question 07

	Tire		Non-Tire		RM		End User	
	Count	%	Count	%	Count	%	Count	%
Yes	127	75.1	27	62.8	34	77.3	47	65.3
No	9	5.3	3	7.0	3	6.8	3	4.2
Don't Know	33	19.5	13	30.2	7	15.9	22	30.6
Total	169	100	43	100.0	44	100	72	100.0

Table 13: Industry wise global response to question 07

	Tire		Non-Tire		RM		End User	
	Count	%	Count	%	Count	%	Count	%
Yes	107	72.3	21	63.6	25	71.4	36	63.2
No	9	6.1	3	9.1	3	8.6	3	5.3
Don't Know	32	21.6	9	27.3	7	20.0	18	31.6
Total	148	100	33	100.0	35	100	57	100.0

Table 14: Industry wise Asia's response to question 07

	Tire		Non-Tire		RM		End User	
	Count	%	Count	%	Count	%	Count	%
Yes	18	94.7	4	66.7	7	100.0	9	75.0
No	0	0.0	0	0.0	0	0.0	0	0.0
Don't Know	1	5.3	2	33.3	0	0.0	3	25.0
Total	19	100	6	100.0	7	100	12	100.0

Table 15: Industry wise Europe's response to question 07

5.4.8 Survey Question 8

Do you think the use of sustainable materials can reduce environmental impacts?

The researcher collated the 330 respondents who answered the question, with 95% believing that using sustainable materials can reduce environmental impact. Only 5% of respondents disagreed that environmentally friendly material usage could reduce environmental effects.

	Global		Asia		Europe		Rest of World	
	Count	%	Count	%	Count	%	Count	%
Yes	312	94.5	261	94.9	40	91	11	100.0
No	18	5.5	14	5.1	4	9	0	0.0
Total	330	100	275	100.0	44	100	11	100.0

Table 16: Region wise response to question 08

Global	Yes		No		Total
	Number	Yes %	Number	No %	Number
Tire	159	95	9	5	168
Non-Tire	40	91	4	9	44
Raw Material	43	98	1	2	44
End User	69	96	3	4	72
Total	311	95	17	5	328
ASIA					
Tire	140	95.2	7	4.8	147
Non-Tire	30	88.2	4	11.8	34
Raw Material	34	97.1	1	2.9	35
End User	56	98.2	1	1.8	57
Total	260	95.2	13	4.8	273
EUROPE					
Tire	17	89.5	2	10.5	19
Non-Tire	6	100.0	0	0.0	6
Raw Material	7	100.0	0	0.0	7
End User	10	83.3	2	16.7	12
Total	40	90.9	4	9.1	44

Table 17: Industry wise response to question 08

Table 16 represents the response count and percentage globally. Table 17 shows the response percentage and number, region wise with a bifurcation of industry. The answer to this question helped the researcher answer the research question of awareness of sustainability among Asian and European regions.

5.4.9 Survey Question 9

According to you, what are the top 5 sustainable materials used in tire industry?

The researcher was trying to collect in-depth knowledge from different stakeholders on sustainable materials by asking this question. Figure 58 gives an overall idea of the response in count as well as in percentage for this question. Out of 332

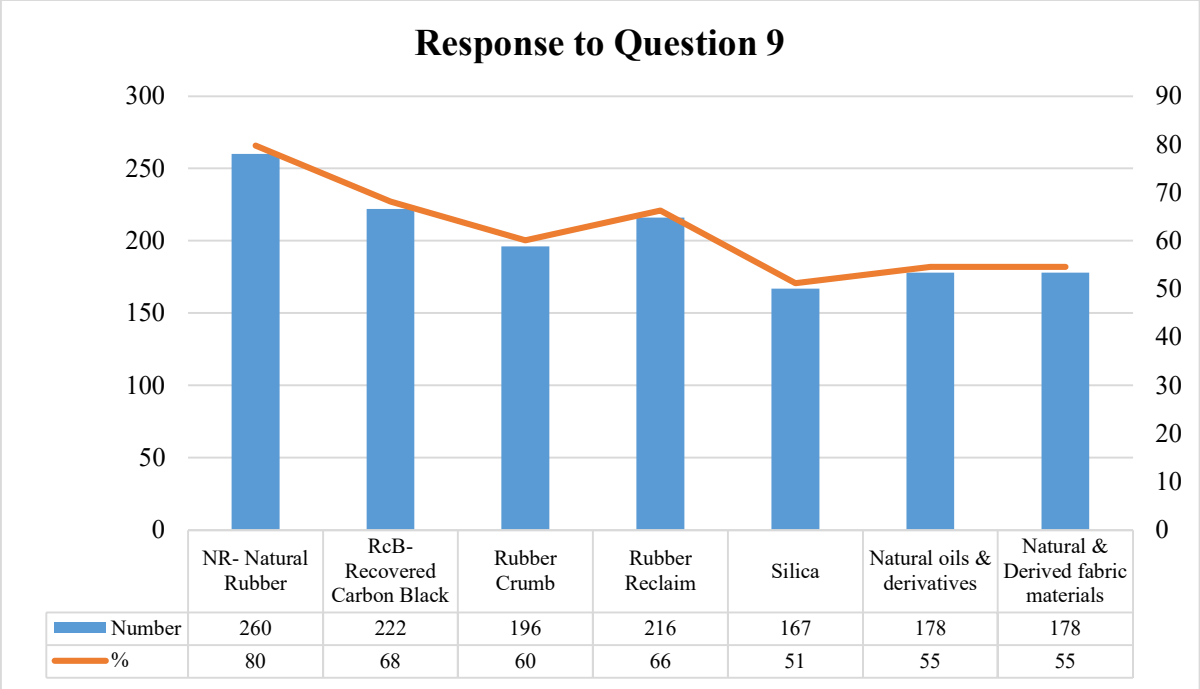


Figure 59: Response to Question 09

respondents, 326 provided their opinions on this topic. 80% of respondents chose natural rubber as their first preference, with RcB at 68%, Reclaim rubber at 66%, Rubber Crumb at 60%, Natural oil, derivatives, and fabrics at 55%, and Silica at 51%. This has enlightened the researcher to answer the research question of awareness and push factors on the implementation of sustainable materials in the tire industry.

5.4.10 Survey Question 10

Do you think the use of sustainable materials in the tire industry impacts the overall carbon footprint of the transportation sector?

The researcher was able to gather 330 responses to this question worldwide. 90% of respondents agreed that incorporating sustainable materials in tire production may decrease the carbon footprint of the transportation industry. Figures 59 and 60 give the details of responses in numbers and percentages respectively.

Even though the majority in the survey agreed that sustainable materials can impact the carbon footprint of the transportation sector, the results of the interview with experts provided clarity on the percentage impact as a minimal level considering the contribution from road transport to the total transportation sector is about 20%, and out of that, 80% is from the combustion of fuels. The researcher could get an in-depth understanding of the percentage contribution of sustainable materials in the transportation sector from the survey as well as the interview answers.

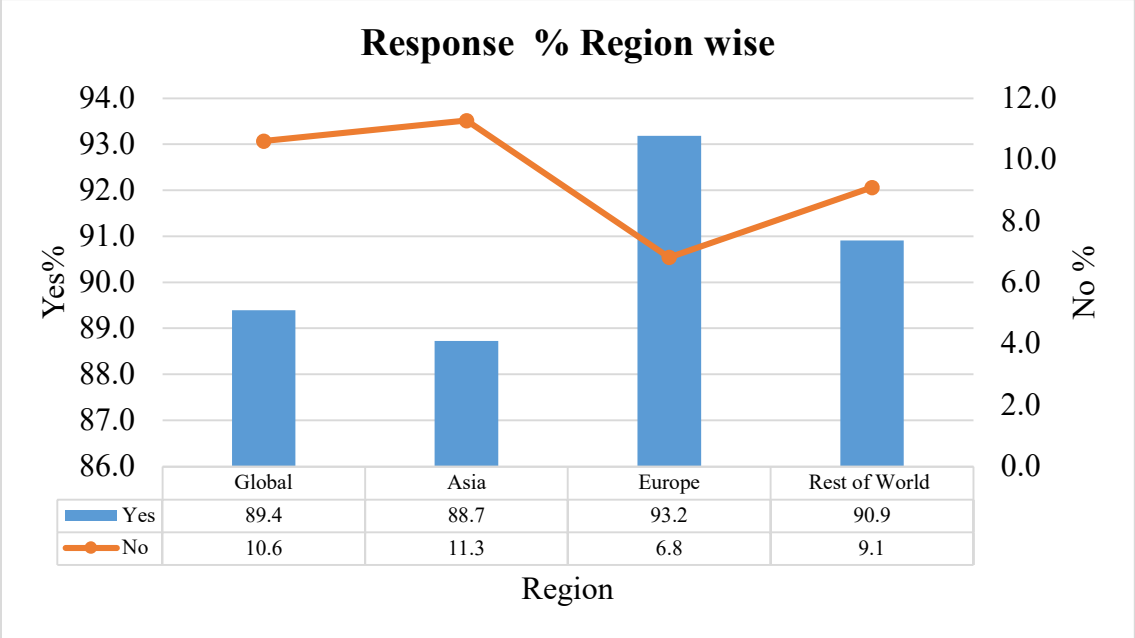


Figure 60: Response % to Question 10

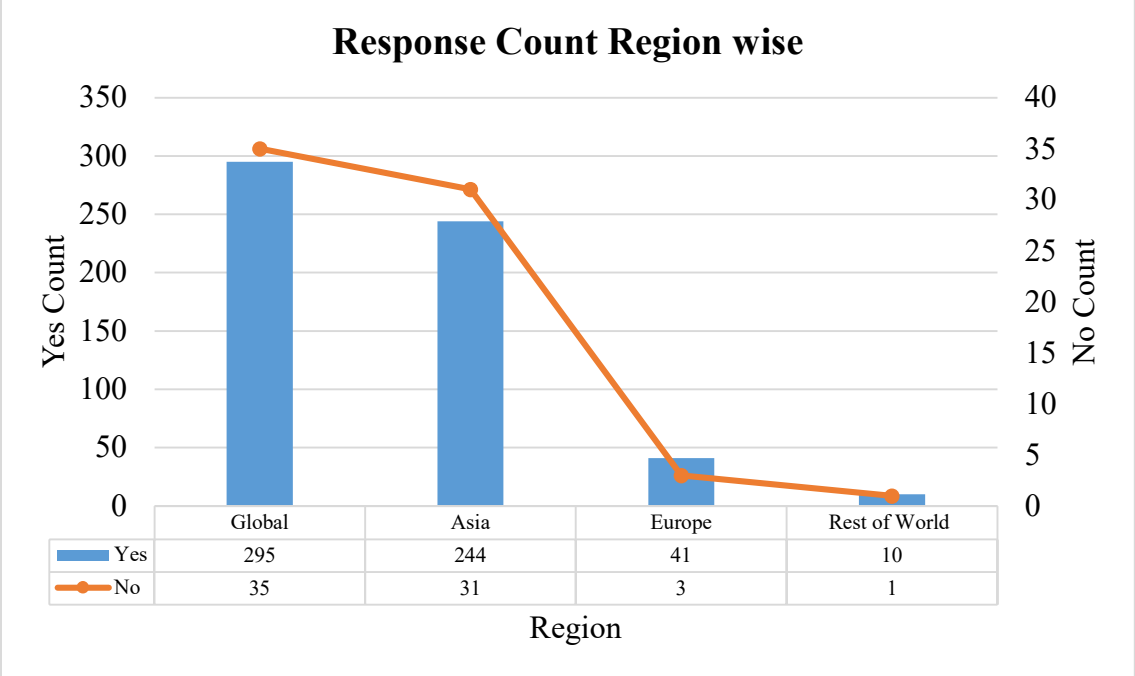


Figure 61: Response count to Question 10

5.4.11 Survey Question 11

Do you think there is a difference in the level of demand for sustainable tires between European and Asian markets?

The researcher collected 329 replies worldwide, with 88% indicating a belief in varying standards for sustainable tires. Table 18 provides an idea of the response received region wise in numbers and percentages. Figures 61 and 62 provide an idea of the response count and percentage region wise. The researcher supported this claim by consulting specialists via direct interviews, which indicated that the European market has a strong demand for sustainable tires, while the Asian market has a low demand. By gathering information about this question, the researcher was able to get an idea about the disparities existing in these tire markets.

	Global		Asia		Europe		Rest of World	
	Count	%	Count	%	Count	%	Count	%
Yes	290	88.1	239	86.9	41	93.2	10	100.0
No	39	11.9	36	13.1	3	6.8	0	0.0
Total	329	100	275	100.0	44	100	10	100.0

Table 18: Region wise response to question 11

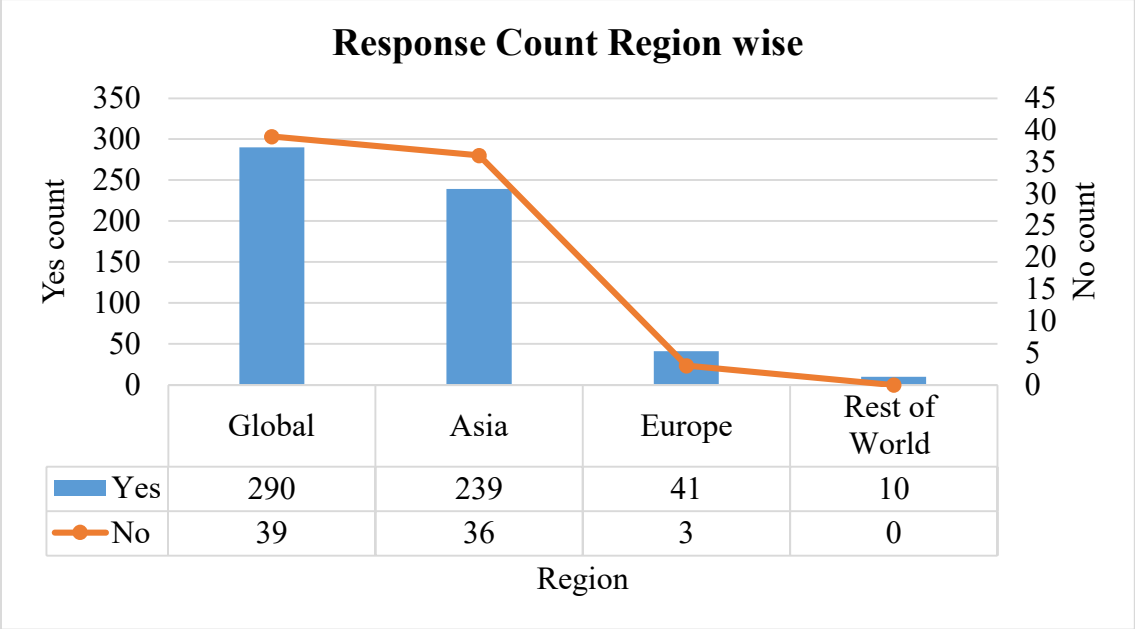


Figure 62: Response count to Question 11

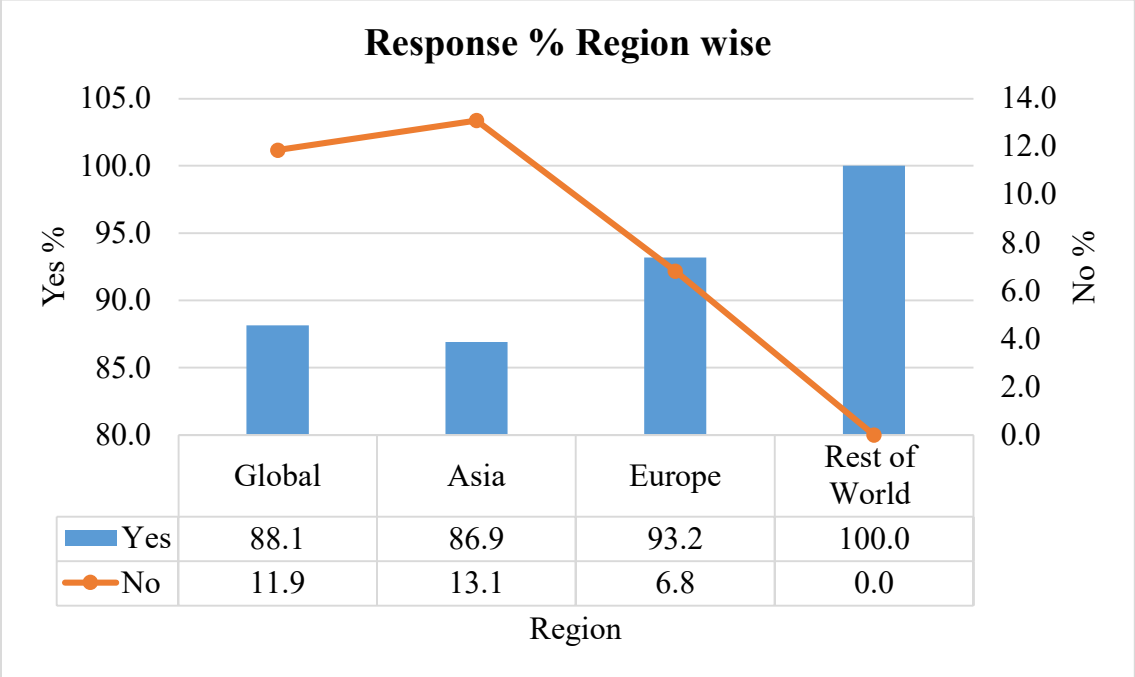


Figure 63: Response % to Question 11

5.4.12 Survey Question 12

How important is it for tire manufacturers to communicate their sustainability efforts to consumers?

The researcher included this question in the survey to understand the stakeholder's perceptions about the transparency of sustainability practices. About 90% of the participants provided ratings of 6 or higher. This emphasises the supreme importance of communicating sustainability efforts to stakeholders. The insights gained from this question could assist tire manufacturers in enhancing their marketing and communication tactics to efficiently promote their sustainability initiatives and cultivate greater consumer trust and involvement with their brand.

	Global		Asia		Europe		Rest of World	
	Count	%	Count	%	Count	%	Count	%
1	3	0.9	3	1.1	0	0.0	0	0.0
2	1	0.3	1	0.4	0	0.0	0	0.0
3	5	1.5	5	1.9	0	0.0	0	0.0
4	4	1.2	4	1.5	0	0.0	0	0.0
5	20	6.1	15	5.6	5	10.6	0	0.0
6	15	4.6	6	2.2	2	4.3	0	0.0
7	27	8.2	26	9.7	0	0.0	1	10.0
8	52	15.8	40	14.9	10	21.3	2	20.0
9	39	11.9	31	11.6	9	19.1	2	20.0
10	163	49.5	137	51.1	21	44.7	5	50.0
Total	**329**	**100.0**	**268**	**100.0**	**47**	**100.0**	**10**	**100.0**

Table 19: Region wise response to question 12

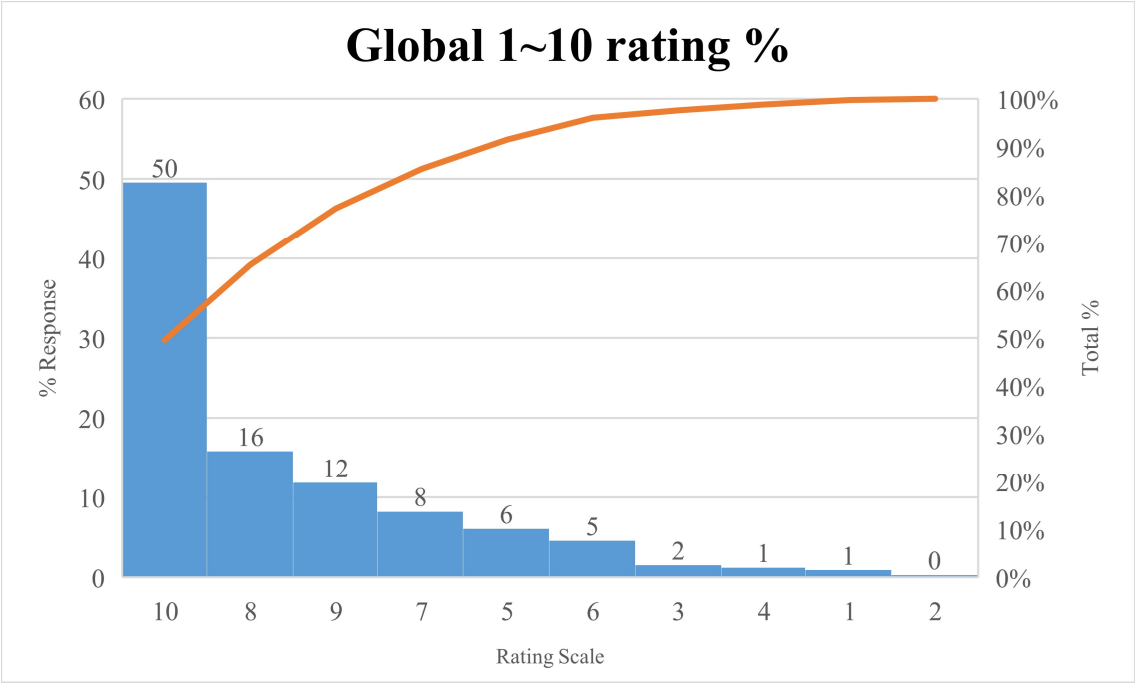


Figure 64: Global 1~10 rating % Question 12

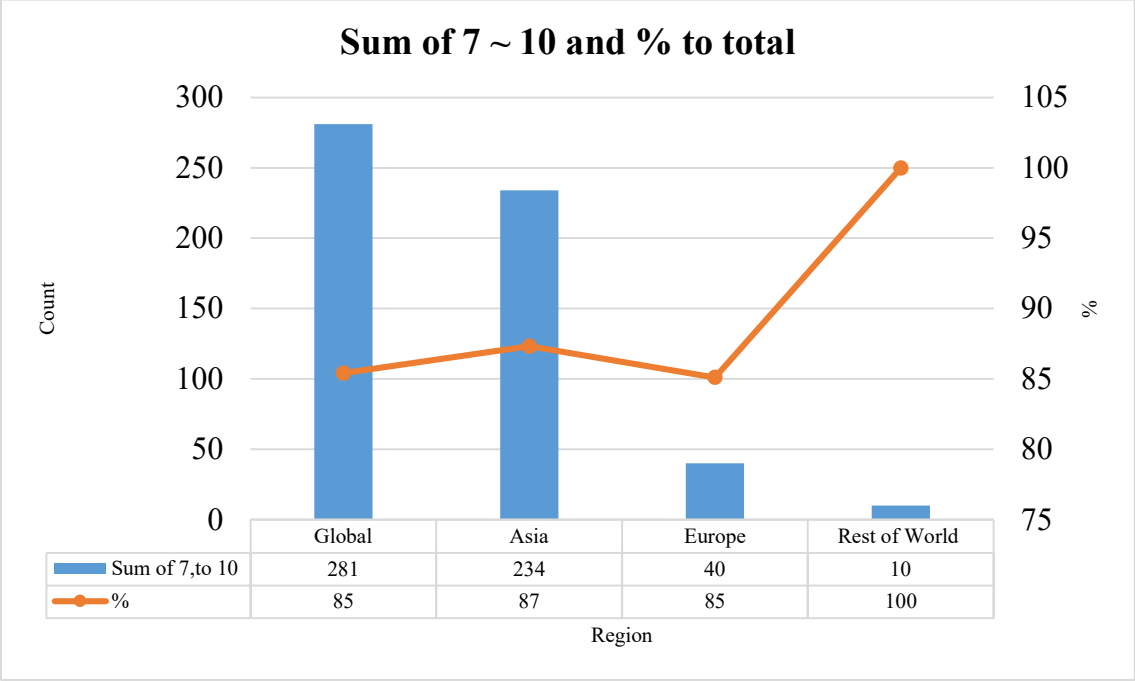
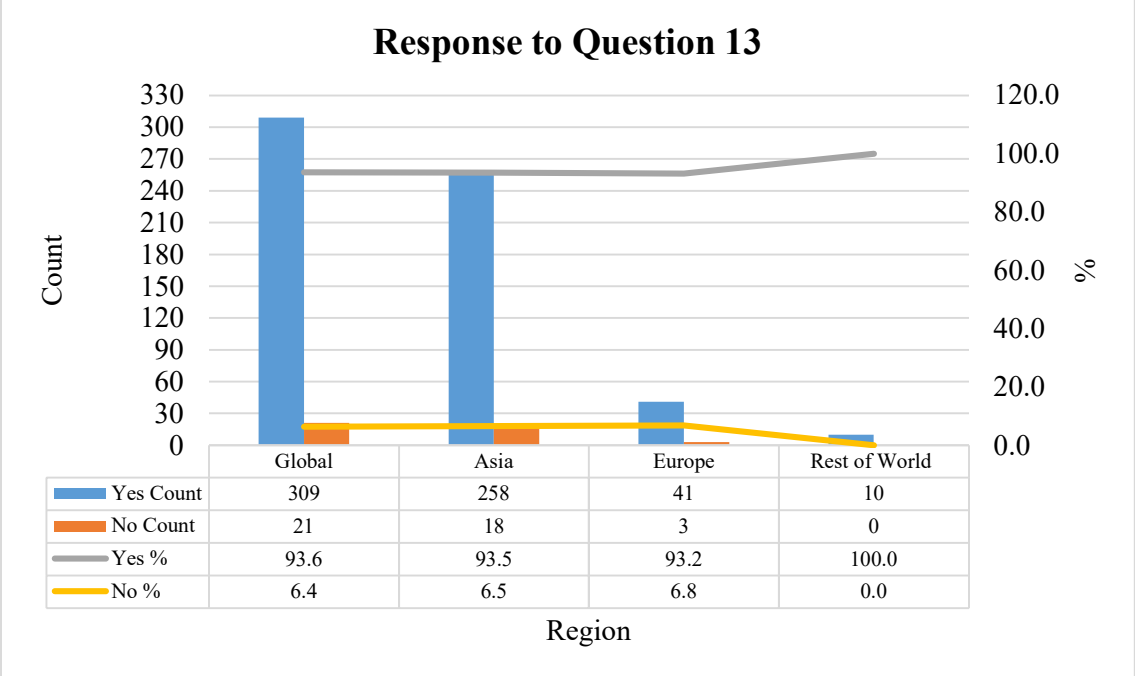


Figure 65: Sum of 7~10 and % to Question 12

5.4.12 Survey Question 13

Do you think tire recycling and retreading play a role in promoting sustainability in the tire industry?

The researcher received a total of 330 replies from individuals all over the world in response to this question. Of those responses, 94% of respondents agreed that recycling and retreading tires may unquestionably assist in promoting sustainability in the tire sector. Figure 65 shows the graphical representation of the response counts as well as percentages region wise. This provided the idea that all the stakeholders, irrespective of the regions, are in alignment with the concepts of re-treading and recycling. This information helped the researcher answer the research question of awareness about sustainability region wise.



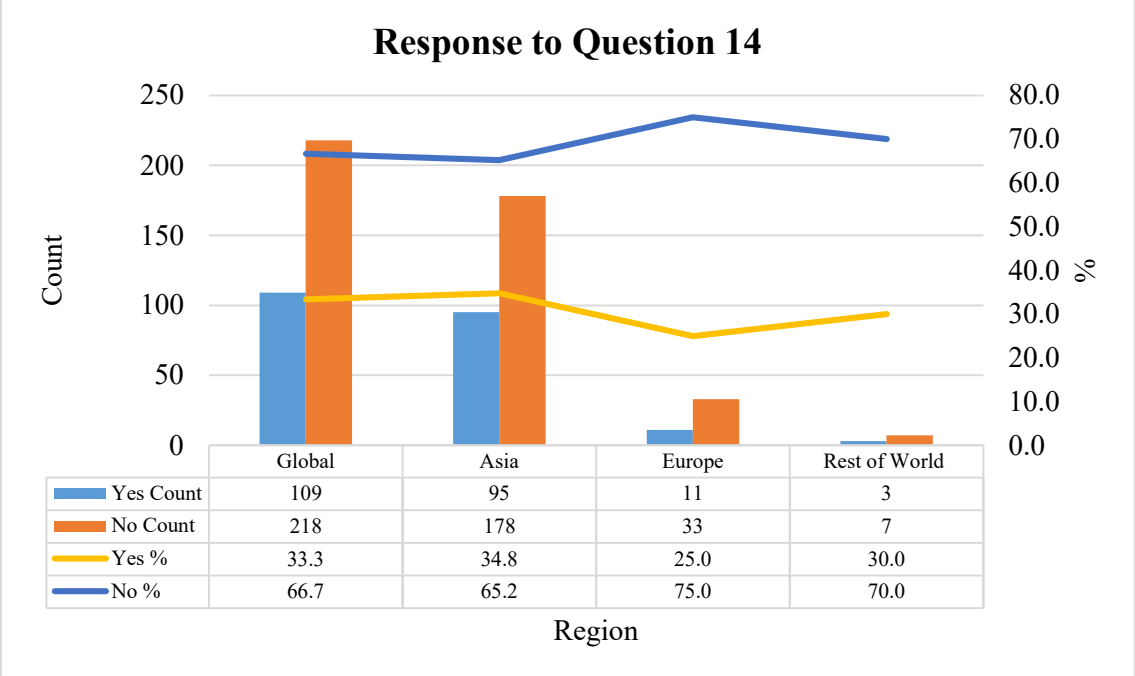
	Global	Asia	Europe	Rest of World
Yes Count	309	258	41	10
No Count	21	18	3	0
Yes %	93.6	93.5	93.2	100.0
No %	6.4	6.5	6.8	0.0

Figure 66: Response to Question 13

5.4.14 Survey Question 14

Do you think 100% implementation of Extended Producer Responsibility (EPR) for tire industry can be done by 2025?

According to the 326 responses, 67% of respondents believed that the goal of implementing Extended Producer Responsibility (EPR) at a rate of 100% was not a realistic target by 2025. On the other hand, 33 percent of respondents stated that it is feasible to implement EPR 100% by the year 2025. Figure 66 provides a graphical representation of the response region wise. This helped the researcher draw a conclusion on the importance of legislative norms and the targets that can promote the implementation of sustainable materials and practices in the tire industry.



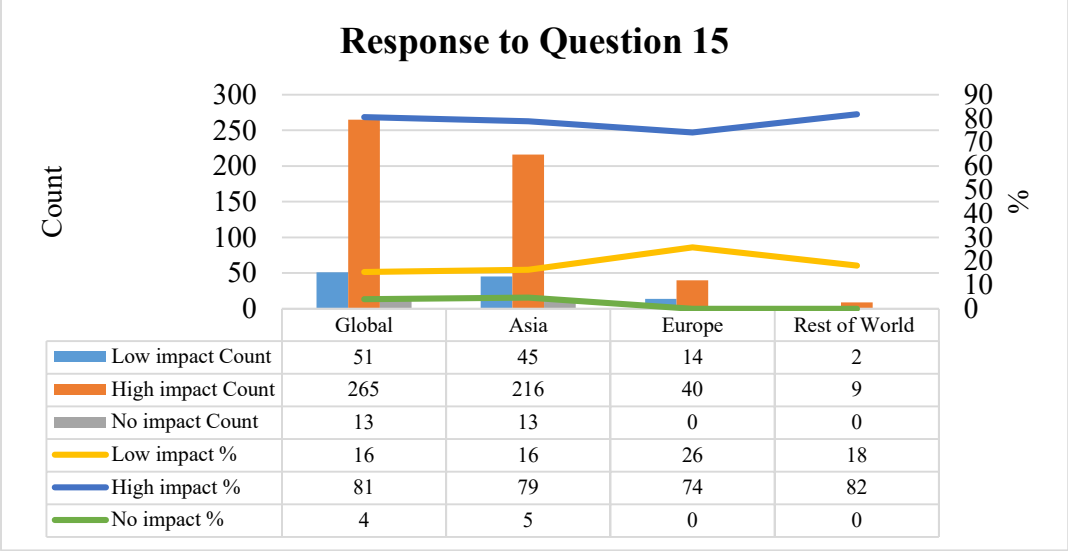
	Global	Asia	Europe	Rest of World
Yes Count	109	95	11	3
No Count	218	178	33	7
Yes %	33.3	34.8	25.0	30.0
No %	66.7	65.2	75.0	70.0

Figure 67: Response to Question 14

5.4.15 Survey Question 15

How do you think the adoption of sustainable materials will impact the future of the tire industry?

The researcher received 329 responses to this question globally. The majority of respondents (80%) were of the opinion that the use of environmentally friendly materials would have a significant influence on the future of the tire industry. The deployment of sustainable materials was thought to have a minor impact on the future of the tire business by 16% of those who participated in the survey. Out of the total respondents, just 4% were of the opinion that there was no impact. Figure 67 provides a graphical representation of the response by count as well as number region wise. Through this question, the researcher gathered valuable information about the awareness of stakeholders about sustainability and material usage.



	Global	Asia	Europe	Rest of World
Low impact Count	51	45	14	2
High impact Count	265	216	40	9
No impact Count	13	13	0	0
Low impact %	16	16	26	18
High impact %	81	79	74	82
No impact %	4	5	0	0

Figure 68: Response to Question 15

5.4.16 Survey Question 16

What steps do you think tire manufacturers can take to increase transparency in their sustainability practices?

The researcher gathered a total of 330 replies for this query; out of those, 72% of respondents are in agreement with the idea of labelling or engraving on the sidewall of the tire, while 57% of respondents stated that advertising can boost the transparency of the sustainable practices that are employed by the tire business. In addition to the packaging, 42% of respondents wanted to see labels integrated into the product. Figure 68 represents the pie chart of the respondents' opinions in number as well as in percentage. The researcher intended to shed light on the innovative methods of communication and sustainability practices tire companies could follow.

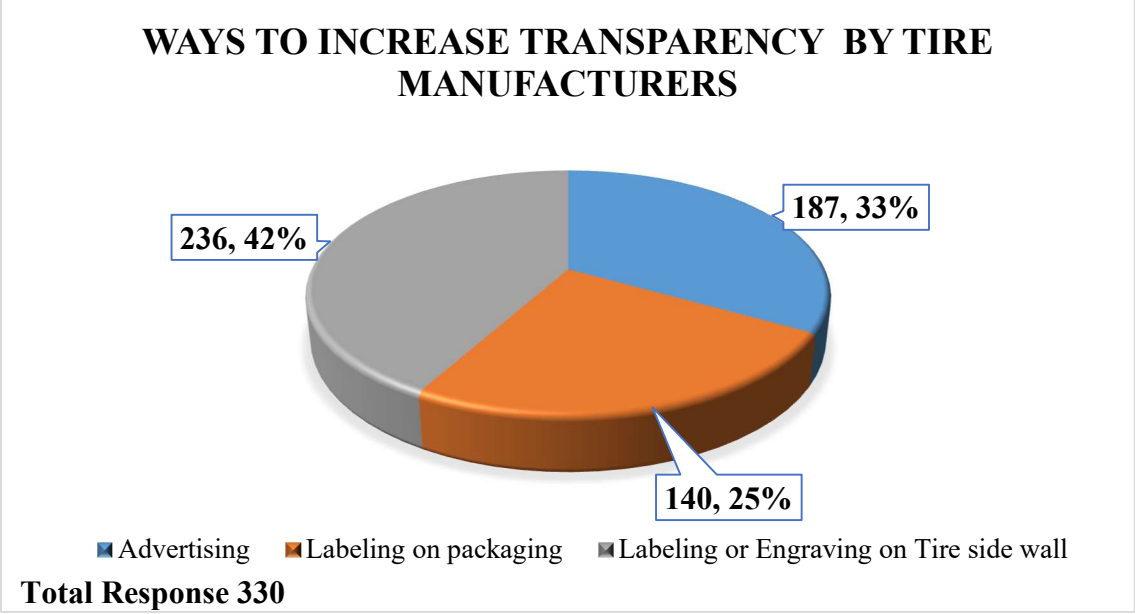


Figure 69: Response to Question 16

5.4.17 Survey Question 17

In your opinion, what is the main barrier to the adoption of sustainable materials in the tire industry?

With regard to adoption of sustainable materials in the tire industry, the researcher obtained a total of 329 replies, and among those responses, 83% of respondents stated that the key obstacles to the adoption of sustainable materials in the tire sector were the availability of raw materials as well as the premium cost of sustainable materials. The remaining respondents believed that the absence of government measures also hindered the deployment of sustainable materials. Figure 69 provides a graphical representation of the response received region-wise.

This is a major input for the researcher, as it helps to answer the research question of factors impending the adoption of sustainable materials in the tire industry. Considering the limitations of the survey, the researcher provided two major reasons out of many for the respondents to reply. Based on the direct interviews of experts from the industry worldwide, the availability as well as the premium cost of the raw material were the major factors impeding the implementation of sustainable materials, along with extensive initial research and validation at the product level

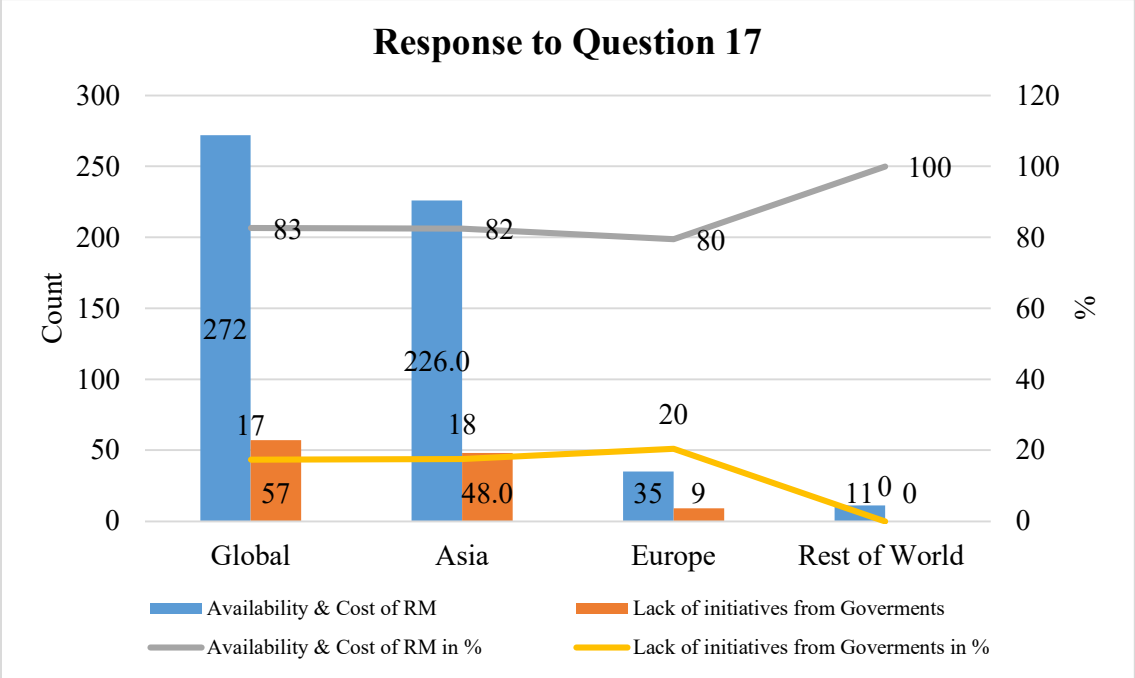


Figure 70: Response to Question 17

5.4.18 Survey Question 18

How would you rate the level of awareness of sustainable materials in the tire industry in Asian markets on a rating scale of 1 to 10?

The researcher received a total of 328 responses for this question, and the overall graph curve is towards the lower side of the scale. This indicates that the awareness of the Asian tire industries requires lots of awareness programs on sustainability initiatives, as the response is towards the lower side of the scale. Figure 70 clearly shows the awareness level in count as well as percentage. This is crucial information for answering the research question of disparities in sustainability initiatives in the Asian region when compared to Europe.

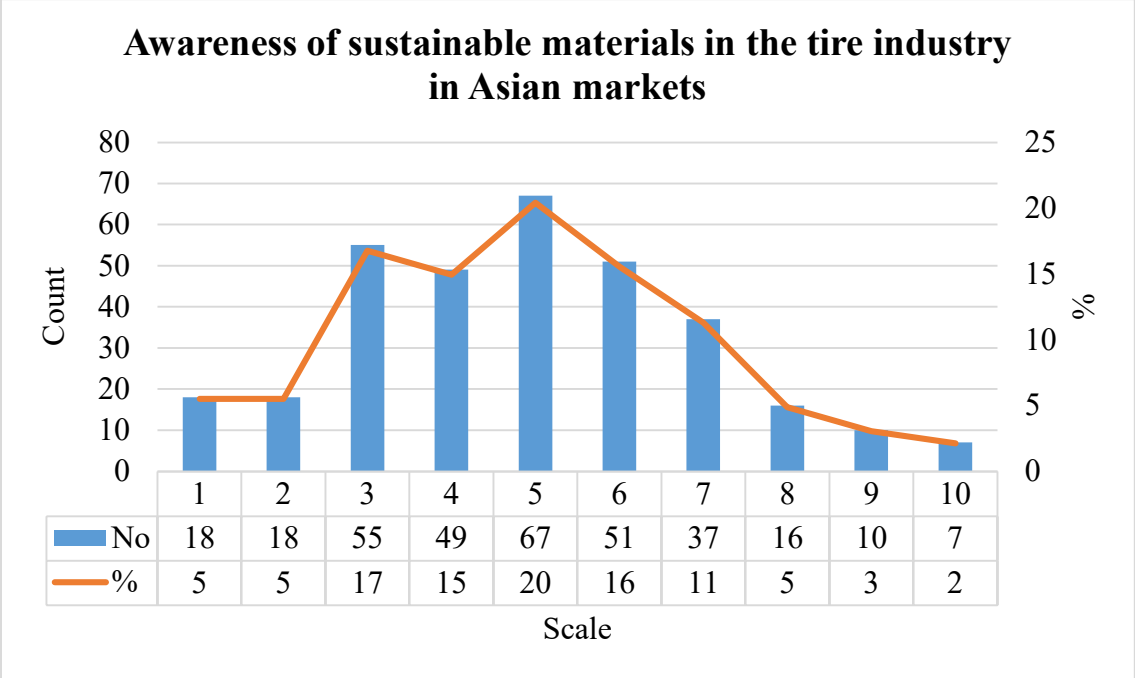


Figure 71: Response to Question 18

5.4.19 Survey Question 19

How would you rate the level of awareness of sustainable materials in the tire industry in European markets on a rating scale of 1 to 10?

In the awareness level of Europe, the researcher utilised a scale and methodology that were comparable to those utilised in the earlier question. The answer to this question was extremely significant in determining the level of awareness that the European market possesses regarding the deployment of sustainable materials. A graphical representation of the responses that were received is given in Figure 71. The graph is moving in the direction of the higher end of the scale, which indicates that there is greater awareness of European markets for sustainability and materials in the tire industry.

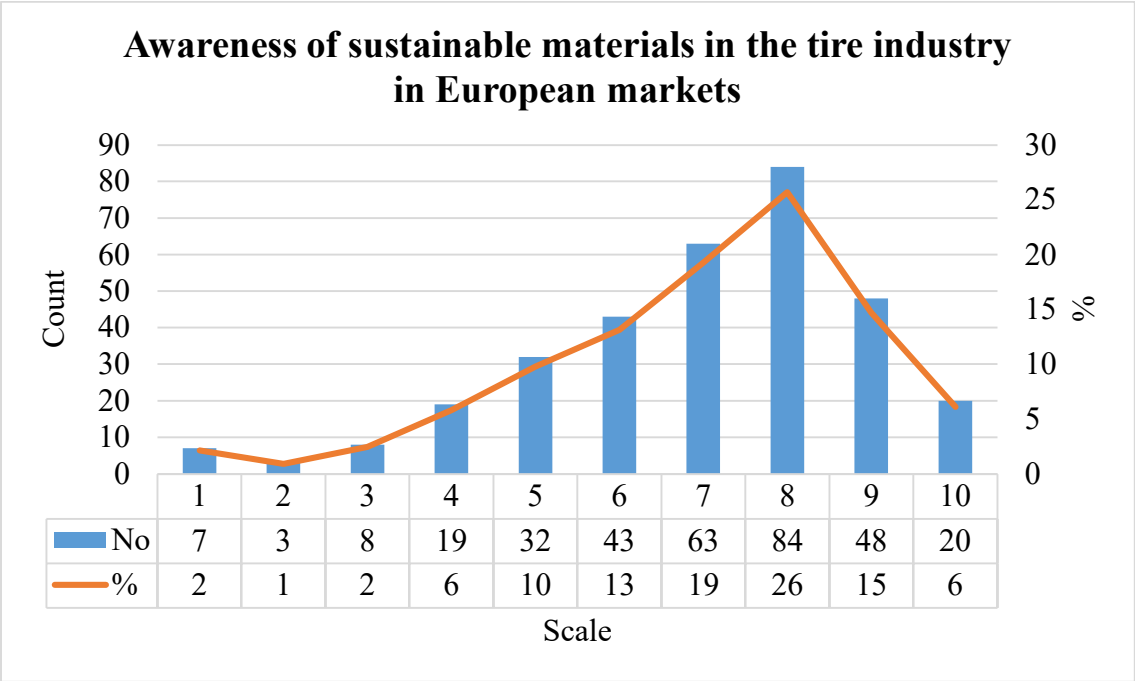
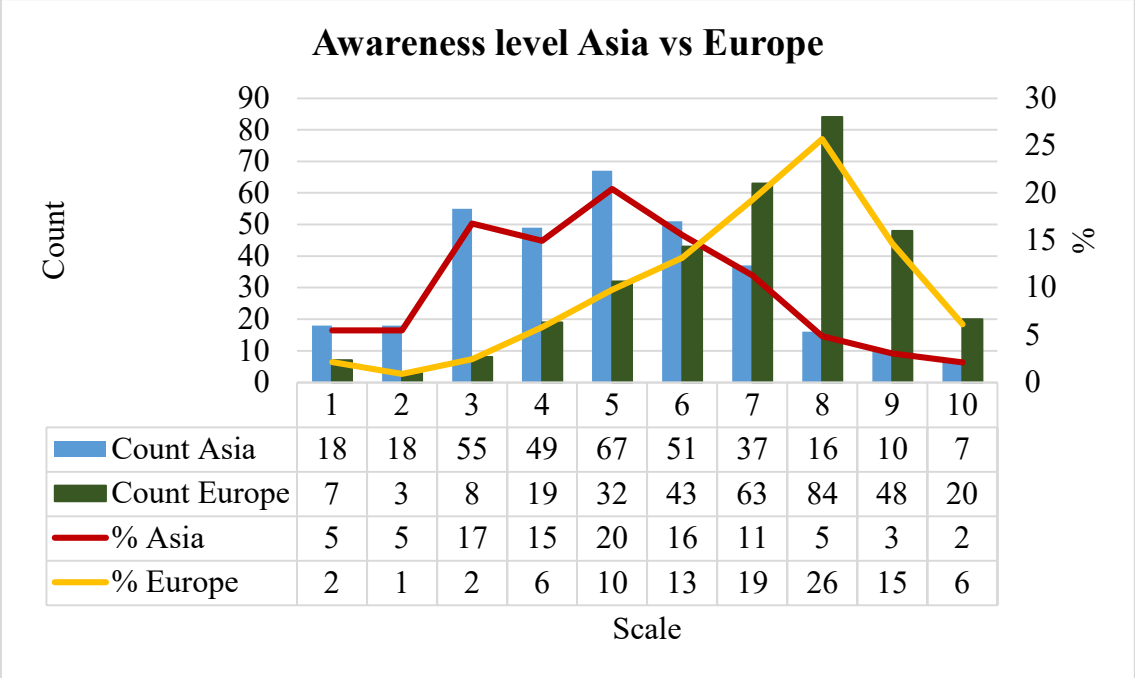


Figure 72: Response to Question 19

Figure 72 gives an overall idea of the comparison of Asian and European markets regarding awareness of sustainable materials and practices. From this diagram, the researcher was able to draw the conclusion that there is a considerable difference in awareness of sustainable materials and practices that are followed in Asian countries as well as European countries. This was one of the research questions that the researcher intended to answer.



	1	2	3	4	5	6	7	8	9	10
Count Asia	18	18	55	49	67	51	37	16	10	7
Count Europe	7	3	8	19	32	43	63	84	48	20
% Asia	5	5	17	15	20	16	11	5	3	2
% Europe	2	1	2	6	10	13	19	26	15	6

Figure 73: Awareness level Asia vs Europe

5.4.20 Survey Question 20

Can you tell us about the identity as an industry person or an end user?

The researcher included this question in the survey in order to segment the data received according to sector. This provided a clear image of the people's perspective on the 19 questions that were provided before, and it could also assist the researcher in analysing the geography of both Asia and Europe with regard to sustainability activities, awareness, and consumer willingness to purchase sustainable tires at a premium price.

The researcher received a good mix of responses in terms of industry from a global perspective. Figure 73 represents the pie chart of the distribution, industry-wise. Figure 74

gives detailed information about the response number as well as the percentages globally with an industry bifurcation. The researcher utilised this information for answering the research questions in consideration of the other survey as well as the interview response.

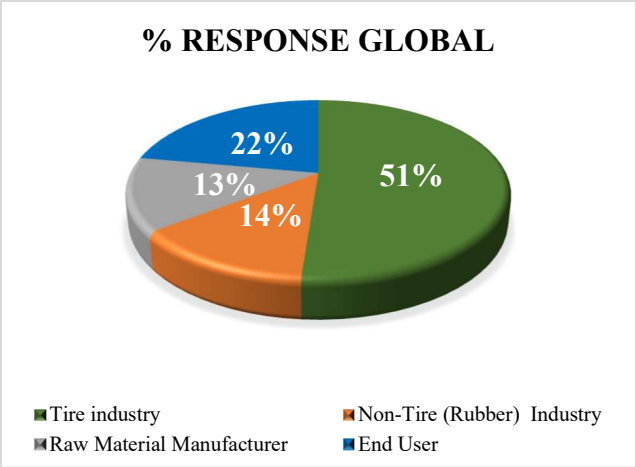
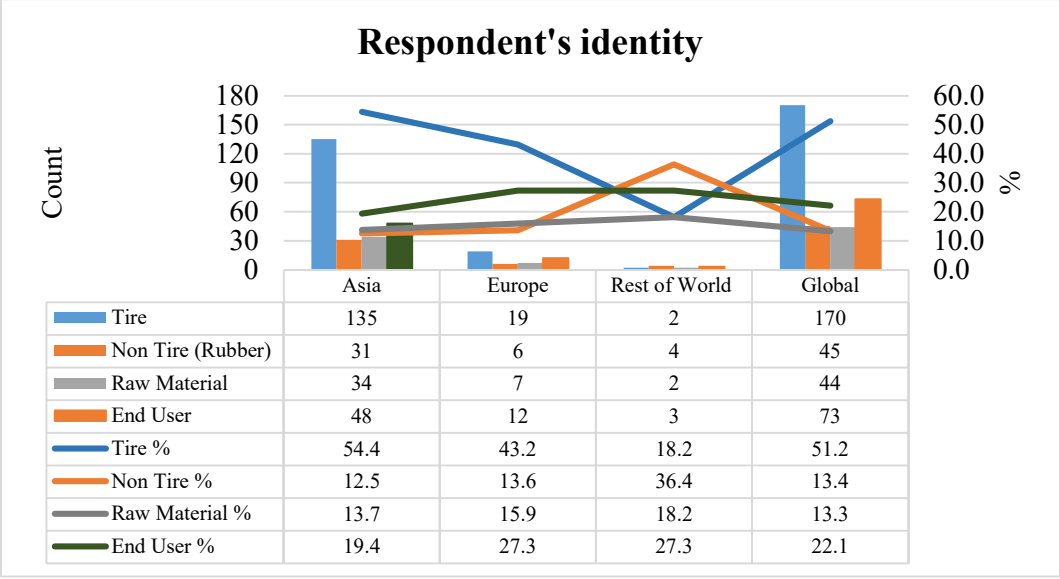


Figure 74: % Response Global Question 20



	Asia	Europe	Rest of World	Global
Tire	135	19	2	170
Non Tire (Rubber)	31	6	4	45
Raw Material	34	7	2	44
End User	48	12	3	73
Tire %	54.4	43.2	18.2	51.2
Non Tire %	12.5	13.6	36.4	13.4
Raw Material %	13.7	15.9	18.2	13.3
End User %	19.4	27.3	27.3	22.1

Figure 75: Respondent's identity question 20

5.5 Discussion of Research Question One

The first research question was, "**What are the disparities in sustainability initiatives and the adoption of sustainable materials in the tire industry between the Asian and European regions?**". The researcher used efficient methodologies like direct interviews, patent searches, sustainability report reviews of tire companies, and a survey among global participants focusing on Asia and Europe. Based on the seven interview questions, the researcher carefully extracted the answer to this question from industry experts. All the interviews were in agreement that Europe is leading the sustainability landscape, while Asia is trying to reduce the gap with Europe through innovations and its fast pace approach towards the implementation of sustainable materials.

The patent search substantiated that Asian regions are leading the innovation space to quickly catch up with Europe and close the gap in sustainability initiatives and material usage. A review of the sustainability reports of tire companies clarified their views on the adoption of the UN's 17 SDGs into their core values and purposes. Incorporating these goals into management practices and the action plans made to achieve them shows the commitments of tire companies. However, the researcher identified the superiority of these activities in Europe, as some of the Asian companies have not yet absorbed the concepts in their full essence. Europe shows a good degree of clarity in terms of GHG emissions, carbon neutrality, the circular economy, and sustainable management practices. The survey results substantiated these concepts with reliable responses, considering the mixed participation around the globe in which all the stakeholders provided their responses to the questions. A good number of 332 substantiate this.

Through a thorough analysis of inputs from interviews, patent searches, sustainability report reviews, and surveys, the researcher identified the main differences between the two regions.

The European regions exhibited a higher level of awareness of sustainability in comparison to Asian countries. This higher level of awareness made the European customers willing to buy sustainable tires at a premium price.

While considering the regulatory frameworks, mature regulatory frameworks and bodies are available in European regions and a few Asian countries, like Japan. However, many other Asian countries are trying to implement these regulatory frameworks for sustainability initiatives like ELT and EPR regulations. Certification on revalidation by third parties is followed in Europe, and in Asian countries, these are self-declarations.

In terms of infrastructure advancement and innovations, Europe is better, and the innovative sustainable materials developed in these regions substantiate this. These premium-priced raw materials are even being imported to Asian countries for use in tires. Specialty carbon blacks for rolling resistance reduction and Graphene from the Netherlands are a few examples.

Another major area where the differences are greater is transparency, sustainable reporting, and management practices. While reviewing the sustainability reports of tire companies, the facts were crystal clear. European tire companies have clearly specified the targets and timeline for the initiated sustainability activities like GHG emissions reduction, carbon footprint reduction, water consumption, and sustainable energy usage. Many Asian

tire companies covered these aspects, but there was a lack of clarity regarding the targets and timelines. However, few Asian tire companies from Japan show maturity in line with European standards and companies.

In conclusion, the European region is leading the sustainable landscape with a considerable gap in awareness, innovation, regulatory framework, and infrastructure, while Asian countries are catching up with Europe through swiftness in sustainable material incorporation into tires and innovations. The researcher was able to answer the research question with the support of information from the methodologies followed during the research process.

5.6 Discussion of Research Question Two

The second research question was, "**What factors promote and impede the adoption of sustainable materials in these markets?**", The researcher utilized the methodologies of direct interview, patent search, sustainability reports review and survey to answer this query.

Based on the expert's interview, the major factors hindering the adoption of sustainable materials were the availability and premium pricing of these materials. The survey results support this statement with solid data. Through the collaborative contribution of tire manufacturers, recyclers, and government bodies, the adoption of sustainable materials can be efficiently promoted. Through innovative products, processes, and sustainable product design, the tire industry can tackle these challenges.

Another major factor impending sustainable material adoption in the tire industry is the extensive research and investment for infrastructure required by tire manufacturers, recyclers, and raw material manufacturers to balance safety and performance while using sustainable materials in tire manufacturing. This can be achieved through the quality improvement of recycled materials through innovative processes and specialty surface treatments and modifications. Moving ahead with these principles can promote the adoption of sustainable materials in the tire industry in a smooth way.

Furthermore, the level of awareness and clarity of the presence of regulatory frameworks and bodies are directly affecting the adoption of sustainable materials in the tire industry. Both the interview and survey substantiate this by pointing out the leadership of Europe, where awareness and infrastructural capabilities are better compared to Asia. The maturity of the ELT management system in Europe enables them to provide greater awareness to the stakeholders, making them willing to pay more for sustainable causes.

In conclusion, the researcher pointed out the factors that are promoting and hindering the adoption of sustainable materials in Asia and Europe. The major factors are availability, premium costs, excessive innovation and investments required, the level of awareness of sustainability, and the lack of government policies. By effectively addressing these areas, sustainable material adoption in the tire industry can be achieved.

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

The researcher aims to shed light on the disparities and the factors promoting and impending adoption of sustainable materials and practices in Asia and Europe. Based on the literature review, the researcher identified a gap in the limited research on comparing Asia and Europe in terms of sustainable material adoption and sustainable practices in the tire industry. The researcher adopted mixed methodologies of interviews, patent searches, sustainability report reviews, and surveys to gather information globally. 51% of the global respondents were from the tire industry, 22% were end users of tires, 14% were from the non-tire segment, and 13% were from raw material manufacturing. This ensured a good mix of participation.

This research has provided significant insights into the current trends, problems, and possibilities regarding the adoption of sustainable materials in the tire industry. Through an in-depth survey and research, the researcher discovered different degrees of awareness, adoption rates, and views about sustainable materials among stakeholders in European and Asian markets. The experts' opinions as well as the survey results substantiated that Europe’s level of awareness of sustainability is higher than that of Asia (refer to Figure 72.) (see Section 5.4 Survey Question 03). However, the Asian regions are leading the innovation space to catch up with Europe. (See Section 5.2.).

The results of the interview, survey, and sustainability report review indicate an increasing acknowledgment of the significance of sustainable practices in the tire sector,

as tire producers are more and more adopting sustainable materials and methods. Many of them incorporated the UN's Sustainable Development Goals (SDGs) into their organisational values and purposes. (See Section 5.3.). Nevertheless, there are major obstacles to general acceptance, such as cost and availability factors, technology constraints, and regulatory intricacies (refer to Figure 69). Despite obstacles, there is a noticeable shift towards sustainability due to rising customer awareness and demand, legal constraints, and a better grasp of the environmental impact of tire production. (Refer to responses to survey questions 13 and 15.). Tire industry players are striving to address these challenges and maximise the opportunities presented by sustainable materials.

Tire companies must prioritise investing in research, innovation, and collaboration with recyclers, raw material manufacturers, and government bodies to overcome obstacles and speed up the use of sustainable materials. Transparency and stakeholder engagement are crucial for establishing confidence and promoting sustainability efforts across the business. Industry experts discussed creative ways to involve stakeholders in sustainability efforts, and the survey results support the information. (See Section 4.3, Survey Question 16).

This research highlights the significance of sustainability in influencing the future of the tire industry. 80% of the total respondents agreed that the adoption of sustainable materials will impact the tire industry's future. (See Section 4.3, Survey Question 15). By emphasising environmental responsibility, social welfare, and economic sustainability, stakeholders can collaborate to establish a more sustainable and enduring industry for future generations.

The survey results, patent search, and sustainability report study supported the expert's opinions, making it easy to identify the factors promoting and preventing the use of sustainable materials in the tire industry. The availability of sustainable materials and their premium pricing stand in first place. The research divisions of tire, raw materials, and recyclers are discussing a variety of innovative materials, but industrializing these materials to ensure their availability has made the adoption of sustainable materials more difficult. These efforts can make recycled materials available at a normal cost to the tire industry. The extensive research required for maintaining the quality of the recycled material as well as the product's safety and performance parameters stands in second place. (See Section 4.1, Interview Question 02.).

6.2 Implications

This research has broad implications that are important for stakeholders in the tire industry and other related industries. This research presents a comprehensive overview of the current state of the tire industry in Asian and European areas.

This research report can be taken into account when tires and related industries are drafting sustainable initiatives and policies. Individuals in the tire sector may use the findings of this research to guide their sustainability plans and product innovation projects. Understanding the present state of sustainable materials adoption and the factors that impact it can assist stakeholders in overcoming obstacles and taking advantage of new opportunities.

Regulatory authorities and policymakers can use the findings of this research to influence rules and regulations that encourage the use of sustainable materials in the tire

industry. The degree of awareness and disparities can be effectively considered for the customised policies region-wise. Policymakers may promote positive change and speed up industry-wide transformation by encouraging sustainability practices, supporting research and development, and establishing sustainability goals.

Customers are crucial to driving demand for sustainable tires; those can be Original Equipment Manufacturer (OEM) or replacement customers. The findings of this study can empower customers to make well-informed purchase choices, prompting them to emphasise tires manufactured from sustainable materials and support companies that exhibit environmental stewardship.

The research highlights the significance of adopting sustainable materials and practices in influencing the future direction of the tire business. Stakeholders may collaborate to overcome difficulties and leverage the opportunities outlined in this research to develop a more sustainable, resilient, and socially responsible tire industry.

6.3 Recommendations for Future Research

The researcher derived recommendations for future research from the findings of this study to enhance the comprehension of sustainable materials in the tire industry and tackle the issues faced. Longitudinal studies can be conducted to monitor the progress of sustainable materials management in the tire industry over time. By analysing the research trends, patterns, and changes in industrial practices, researchers can understand the lasting effects of sustainability efforts and thus identify areas for ongoing advancement.

In light of the findings of this research, life cycle assessments (LCAs) can be performed in the tire industry to analyse the environmental, social, and economic effects

of sustainable materials across the whole product lifecycle. This is not religiously followed now. This can help the organization assess its overall sustainability performance.

Furthermore, studies on consumer viewpoints, beliefs, and actions on sustainable tires through thorough behavioural research can be initiated. Studying consumer preferences, decision-making processes, and willingness to pay for sustainable products can guide marketing tactics, product positioning, and market segmentation.

These research findings can also be considered for directing innovations towards sustainable materials by tire companies and recyclers. Those studies can enhance the sustainability of the tire industry. The findings can be a reference guideline for policymakers in the tire and allied industries. This can be effectively utilised for enhanced stakeholder management.

Following the suggestions for future study, scholars, tire industry experts, and policymakers may help progress sustainability in the tire industry and aid the shift towards a more resilient, fair, and sustainable future.

6.4 Conclusion

This research on sustainable materials in the tire industry, a cross-continental comparative study of Europe and Asian markets, provided useful insights on the acceptance, awareness, and use of sustainable materials in the tire industry. The outcomes highlight the growing understanding and significance of sustainability practices among tire makers, along with the challenges and opportunities that are linked to the incorporation of sustainable materials into the tire manufacturing process.

The researcher employed a mixed-methods approach to evaluate the viewpoints of different stakeholders from various parts and professions across the globe, revealing the wide range of factors that impact the adoption of sustainable materials. Continued research, collaboration, and innovation are crucial for advancing progress in creating a more sustainable tire industry. The tire industry may improve its green credentials, social responsibility, and financial sustainability by overcoming these obstacles, leveraging technological breakthroughs, and involving the entire spectrum of stakeholders. The researcher was able to answer the research questions about disparities as well as the challenges of adopting sustainable materials in the tire industry.

As a final conclusion, the comparison of Asian and European regions with regard to the adoption of sustainable materials revealed the current gap between these two regions, which tire and related manufacturers can effectively close in cooperation with governing bodies. This research contributes to the overall discussion on sustainability in the tire industry as a comparison between Asia and Europe and establishes a basis for future studies focused on promoting sustainable practices and material usage encouraging constructive developments. This can ensure a brighter and greener future for the tire industry and for society as a whole.

APPENDIX A

SURVEY COVER LETTER

Survey on Sustainable Materials in Tire Industry

Dear respondents,

I am a doctoral research scholar at SSBM Geneva, seeking your valuable participation in a survey that forms an integral part of my doctoral thesis data collection.

The purpose of this survey is to gather insights and opinions on the topic of sustainable materials and their application in the tire industry, with a focus on understanding regional differences between the European and Asian markets.

If you are involved in the tire industry, automotive industry, raw material industry, or if you are an end user of tires, I kindly request your assistance in completing this survey.

Your input is incredibly important, and I would greatly appreciate it if you could spare approximately 10 minutes of your time to answer the provided questions.

Thank you very much for considering my request, and for your valuable time.

Survey Link: https://forms.gle/CGZAkyc4FU3NZFwG7

Albin Antony albin@ssbm.ch

APPENDIX B

INFORMED CONSENT

Interview Consent Form

Research project title: **Sustainable materials in Tire industry, a comparative study of European and Asian markets**

Research investigator: Mr.Albin Antony albin@ssbm.ch

Research Participants name: Mr.Name name@domain.com

The interview may take 30 minutes. We don't anticipate that there are any risks associated with your participation, but you have the right to stop the interview or withdraw from the research at any time.

Thank you for agreeing to be interviewed as part of the above research project. Ethical procedures for academic research require that interviewees explicitly agree to being interviewed and how the information contained in their interview will be used. This consent form is necessary for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Would you therefore read and then sign/agree this form to certify that you approve the following:

- The interview will be recorded and a transcript will be produced
- You will be sent the transcript and given the opportunity to correct any factual errors
- The transcript of the interview will be analysed by Mr.Albin Antony as research investigator
- Access to the interview transcript will be limited to Mr.Albin Antony and academic

mentor with whom he might collaborate as part of the research process

- Any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed
- The actual recording will be kept until the thesis is approved and the doctoral degree is granted.
- Any variation of the conditions above will only occur with your further explicit approval

All or part of the content of your interview may be used;

- In academic papers and thesis report and in an archive of the project as noted above.

By signing this form, I agree that;

1. I am voluntarily taking part in this project. I understand that I don't have to take part, and I can stop the interview at any time;
2. The transcribed interview or extracts from it may be used as described above;
3. I don't expect to receive any benefit or payment for my participation;
4. I can request a copy of the transcript of my interview and may make edits I feel necessary to ensure the effectiveness of any agreement made about confidentiality;
5. I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

Participant Name: Name name@domain.com **Date :**

Participants Signature/Agreement

Researcher Name: Albin Antony **Date:**

RESEARCHERS SIGNATURE DATE

Contact Information

This research has been reviewed and approved by the SSBM Geneva, Swiss School of Business and Management Research Ethics Board. If you have any further questions or concerns about this study, please contact:

Name of researcher : Albin Antony Maniyarankudy, Idukki, Kerala, India
Tel: +91 8291184708 E-mail: albin@ssbm.ch
You can also contact Mr.Albin Antony's supervisor: Dr.Anna Provodnikova
Full address : SSBM Geneva, Swiss School of Business and Management
GBC - Geneva Business Center, Avenue des Morgines 12, 1213 Genève, Switzerland
Tel: +41 (0)22 508 7796 - E-mail: anna@ssbm.ch

WHAT IF I HAVE CONCERNS ABOUT THIS RESEARCH?

If you are worried about this research, or if you are concerned about how, it is being conducted, you can contact SSBM by email at contact@ssbm.ch

APPENDIX C

INTERVIEW GUIDE

The interview will be recorded and a transcript will be produced

- You will be sent the transcript and given the opportunity to correct any factual errors
- The transcript of the interview will be analysed by Mr.Albin Antony as research investigator
- Access to the interview transcript will be limited to Mr.Albin Antony and academic mentor with whom he might collaborate as part of the research process
- Any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed
- The actual recording will be kept until the thesis is approved and the doctoral degree is granted.
- Any variation of the conditions above will only occur with your further explicit approval

All or part of the content of your interview may be used;

· In academic papers and thesis report and in an archive of the project as noted above.

By signing this form I agree that;

1. I am voluntarily taking part in this project. I understand that I don't have to take part, and I can stop the interview at any time;

2. The transcribed interview or extracts from it may be used as described above;

3. I don't expect to receive any benefit or payment for my participation;

4. I can request a copy of the transcript of my interview and may make edits I feel necessary to ensure the effectiveness of any agreement made about confidentiality;

5. I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

Question Number	Question
Q1	To what extent does government policies contribute to the promotion of sustainable materials in the tire sector ?
Q2	What are the key challenges that tire producers need to overcome in order to incorporate sustainable materials ?
Q3	How does the utilization of sustainable materials by the tire industry impact the overall carbon footprint of the transportation sector and to what extend?
Q4	How do tire producers find a balance between using sustainable materials and complying with safety and performance regulations?
Q5	What are the potential avenues for technological advancements and innovations in the use of sustainable materials within the tire industry?
Q6	What measures can tire manufacturers adopt to enhance transparency in their sustainable practices?
Q7	How do the European and Asian markets compare in terms of the adoption and utilization of sustainable materials in the tire sector?

APPENDIX D

SURVEY GUIDE

Email *

Record **albin@ssbm.ch** as the email to be included with my response

Survey on Sustainable Materials in Tire Industry; comparison between Asian and European markets

SSBM GENEVA

Country you are residing ? *

Choose

Do you think sustainable materials will become the norm in the tire industry in the future?

- ◯ Yes
- ◯ No

Which tire market is leading the adoption of sustainable materials usage ?

- ◯ Europe
- ◯ Asia

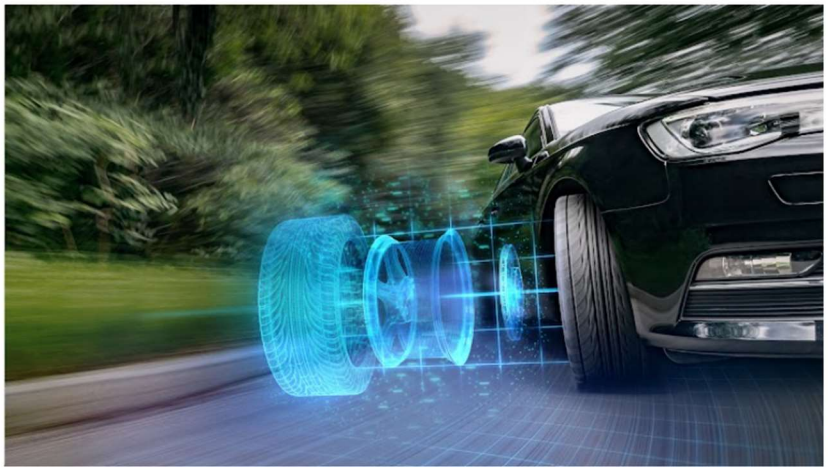
As an end user are you willing to buy a tire with sustainable materials at a higher cost?

- ◯ Yes
- ◯ No

Do you think Asian government's are making policies in promoting sustainable material usage?

- ◯ Yes
- ◯ No

Do you think the usage of sustainable raw materials can affect the tire performance and quality ?



- ◯ Improves with usage of sustainable materials
- ◯ Deteriorates with usage of sustainable materials
- ◯ No idea

Do you think tire producers can ensure the tires made from sustainable materials will have both durability and excellent performance?

- ◯ Yes
- ◯ No
- ◯ Don't know

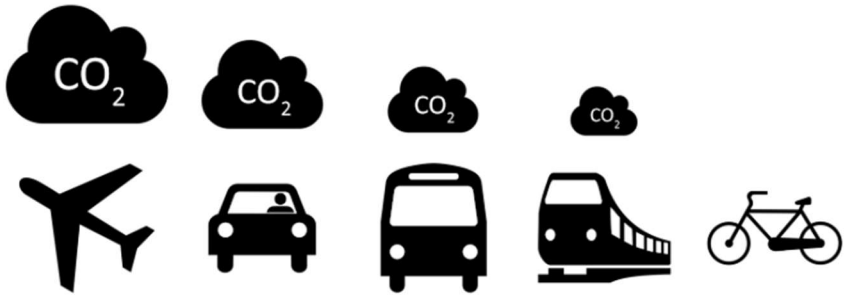
Do you think the usage of sustainable materials can reduce the environmental impacts ?

- ◯ Yes
- ◯ No

According to you, what are the top 5 sustainable materials used in tire industry ?

- ☐ NR- Natural Rubber
- ☐ RcB- Recovered Carbon Black
- ☐ Rubber Crumb
- ☐ Rubber Reclaim
- ☐ Silica
- ☐ Natural oils & derivatives
- ☐ Natural & Derived fabric materials

Do you think the use of sustainable materials in the tire industry impact the overall carbon footprint of the transportation sector?



- ◯ Yes
- ◯ No

Do you think there is a difference in the level of demand for sustainable tires between European and Asian markets?

- ◯ Yes
- ◯ No

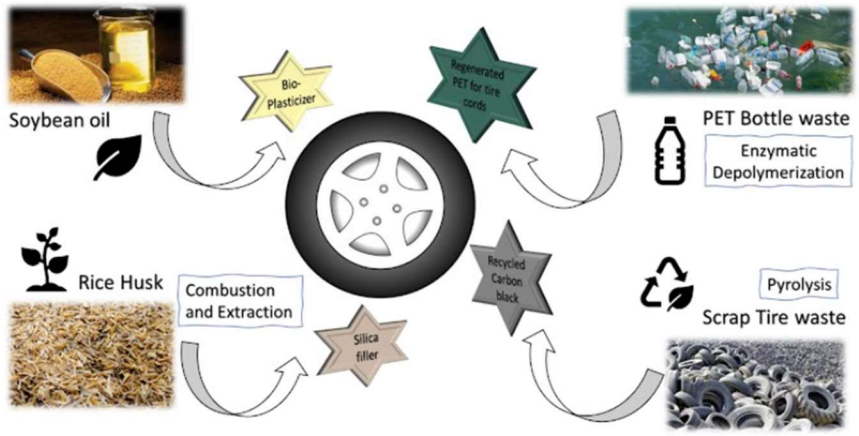
How important is it for tire manufacturers to communicate their sustainability efforts to consumers?

	1	2	3	4	5	6	7	8	9	10	
Lowest	○	○	○	○	○	○	○	○	○	○	Highest

Do you think tire recycling and retreading play in promoting sustainability in the tire industry?

- ○ Yes
- ○ No

How do you think the adoption of sustainable materials will impact the future of the tire industry?

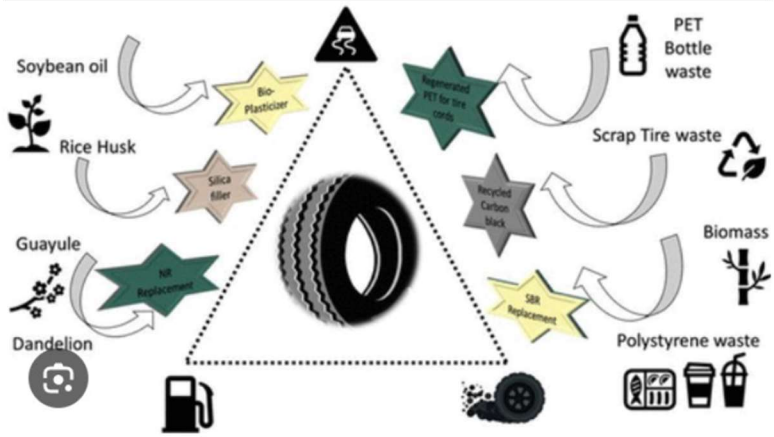


Choose

What steps do you think tire manufacturers can take to increase transparency in their sustainability practices?

- [ ] Advertising
- [ ] Labeling on packaging
- [ ] Labeling or Engraving on Tire side wall

In your opinion, what is the main barrier to the adoption of sustainable materials in the tire industry?



- [ ] Availability & cost of sustainable Raw Materials
- [ ] Lack of initiatives from Government's

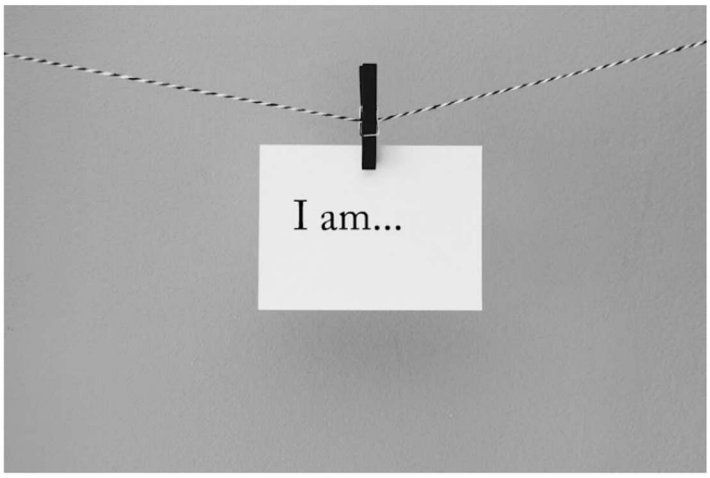
How would you rate the level of awareness of sustainable materials in the tire industry in Asian markets in a rating scale of 1 to 10?

	1	2	3	4	5	6	7	8	9	10	
Lowest	○	○	○	○	○	○	○	○	○	○	Highest

How would you rate the level of awareness of sustainable materials in the tire industry in European markets in a rating scale of 1 to 10?

	1	2	3	4	5	6	7	8	9	10	
Lowest	○	○	○	○	○	○	○	○	○	○	Highest

Can you tell us about the identity as an industry person or an end user ?



- ○ From Tire Industry
- ○ From Non Tire sector
- ○ From Raw Material Manufacturing
- ○ An End User

APPENDIX E

PUBLICATIONS

"SUSTAINABLE MATERIALS IN TIRE INDUSTRY: A COMPARATIVE STUDY OF EUROPE AND ASIAN MARKETS"

2021: International Conference on Business and Integral Security (IBIS) 2021,

Available at: http://gbis.ch/index.php/gbis/article/view/33

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