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

Research Paper

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Abstract

The current research focuses on collecting and reviewing research papers from reliable data bases like Science Direct, Research Gate, Google Scholar, WBCSD, TIP and Sustainability reports of tire manufacturing majors worldwide. Tire and automobile industry is an integral part of today's mobility. Tire industry made a good compound annual growth rate (CAGR) during 2015-2020 and the current CAGR prediction for the period 2021-2016 is 4%. World Tire production volume in 2020 was 3.38 billion units, the forecast during 2021-2026 is to reach about 4.11 billion units per year. Asia-pacific region is the biggest automotive tire supplier with a volume share of around 59% and Europe is the second largest automotive tire manufacturer with a volume share of around 17%. Asia-Pacific, Europe and North America are the biggest consumers of automotive tires. This study will help to track and overcome if there are gaps in the sustainable move.

Keywords: Sustainability, Sustainable materials, ELT, Sustainable Raw Materials, Tire, Regenerated Materials, Tire Industry Project.

1. Introduction

Automotive tire manufacturing industry is one of the world's biggest industry (IBIS World, 2021). In the current scenario, world cannot imagine a life without tire and automobile sector, ever since the invention of the automotive vehicles and tires. As the industry is growing, the raw material consumption is also proportionately growing. Manufacturing industries contribute towards global warming by means of carbon dioxide (CO_2) emission, ground water consumption and consuming the non-renewable resources from the nature (Bridgestone Corporation, 2021). Industries started initiatives to reduce the raw material consumption for automotive tire production, considering reducing the impact to the nature (Imarcgroup, 2021). Carbon neutrality is targeted by world's major tire industries by 2030 (Ktvn, 2021), (Bridgestone Corporation, 2021). This is planned by reducing the raw material consumption, reducing the tire weight and improving the quality parameters, increasing the consumption of natural and renewable resources and reducing the dependency from the resources of petroleum origin (Bridgestone

Corporation, 2021). Further, industry is increasing its energy efficiency and reducing non-renewable energy source. Manufacturing and mechanical inventions also contributes a lot in to this objective.

The 4R (Reduce, Recycle, Re-use, Renewable) and the upgraded version 7R (Reduce, Recycle, Re-use, Renewable, Redesign, Repair and Recover) principles are the key to achieve the target of tire production from 100% sustainable materials and reduced carbon emission by 2030 (Zhongming et al., 2021), (Araujo-Morera et al., 2021). Many, out of the box tire concepts like Tweel by Michelin, No air by Toyo, Airless by Bridgestone, I-Flex by Hankook etc. are also introduced by tire majors to become more sustainable and carbon neutral by 2030.

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

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

Linear Economy (LE) (Fig.02) deals with the disposition of the product after end of the life is contributing pollutants to the nature. Moving with Circular Economy (CE) (Fig.01) will take the industry closer to its commitments towards the Sustainable Development Goals (SDGs) which starts with the selection of sustainable, recyclable and reusable raw materials, design and development of the tire, and End of Life Tire - ELT (WBCSD, 2021). The CE will enhance the longevity and improve the performance characteristics of the tire as well as reducing the impact to the nature by reducing the final disposal to the nature through the circular process of recycling, recovering, reusing, repairing and redesigning. The composition of vehicle tire materials in percentage (%) (Fig.03 & Fig.04) are given below, is of prime importance in the ELT management considering material and energy recovery.

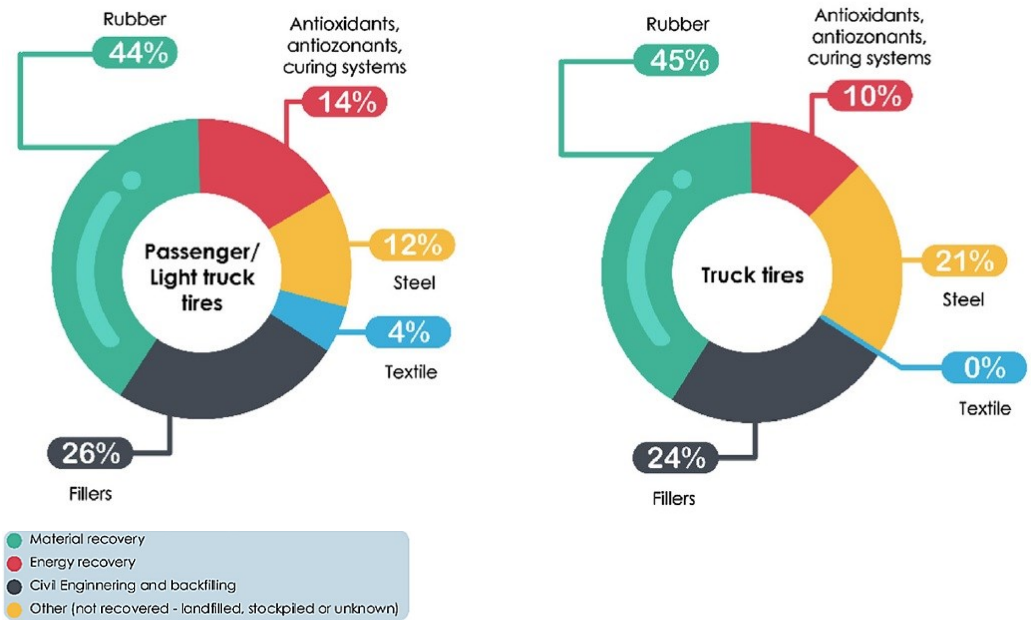

Fig 03. Composition of Vehicle Tire Materials in percentage (%). (Araujo-Morera et al., 2021)

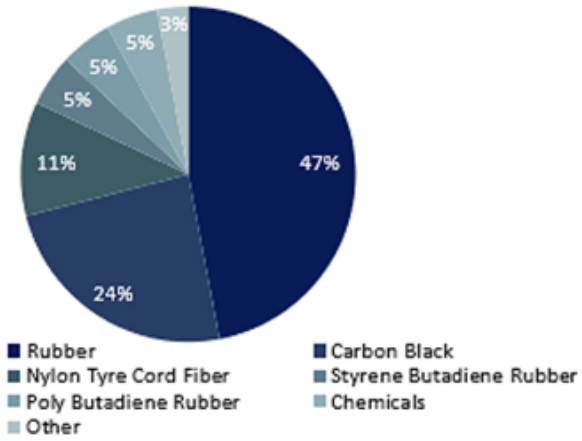

Fig 04. Composition of 2/3 Wheeler Tire Materials in percentage (%) (Satija A, 2021)

2. Context of Research

Tire and tire industry are essential in the present scenario for mobility. Tire is a composite structure, which consists of many assembled components, which are made of many raw materials including; polymers, fillers, reinforcement materials like, natural and synthetic fabrics and steel cords, process aids and plasticizers like process oils and metallic stearates and vulcanizing chemicals and accelerators (Kumar and Nijasure, 1997). In addition to this there are many other chemicals are in place, which optimizes the process, enhances the compound safety, retains and improves the chemical, physical and mechanical properties of the vulcanized or cured rubber. Synthetic polymers, carbon blacks and rubber process oils are of petroleum origin and are non-renewable.

Classification of tire industry raw materials in to two for the present study as, sustainable and non-sustainable direct and indirect raw materials. 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 sustainable material usage can reduce the carbon foot print, which is defined as 'It is the measure of exclusive total amount of green-house gases emission including carbon dioxide, that is directly and indirectly caused by an activity or it is accumulated over the life stage of a product' (Wiedmann and Minx, 2008). Global tire manufacturers sets target to achieve carbon neutral or zero carbon footprint target by 2030 and manufacturing of tire from 50% sustainable raw materials by 2030 (Bridgestone Corporation, 2021). World Business Council for Sustainable Development (WBCSD) has set up the Tire Industry Project (TIP) in association with the major global tire manufactures and Sustainable Development Goals (SDGs) for Tire Industry (WBCSD, 2021).

Present study focuses on comparing the achievements and readiness for fulfilling the sustainable targets set by WBCSD and global tire majors in the biggest tire manufacturing and consuming regions globally; Asia-Pacific and European markets (Fig. 05). About 60% of the world's tire manufacturing plants located in Asian continents (Satija A, 2021). China, India, Thailand, Taiwan, Vietnam and Indonesia are the major manufacturing countries in the Asia-Pacific region. European tire industry is also in the growth phase. Countries like Germany, France, Poland, UK, Spain and Italy are contributing about 60% of the total sales in European region. This deals with the raw materials usage strategies and End of Life Tire (ELT) management along with the indirect and direct material sourcing policies (WBCSD, 2021).

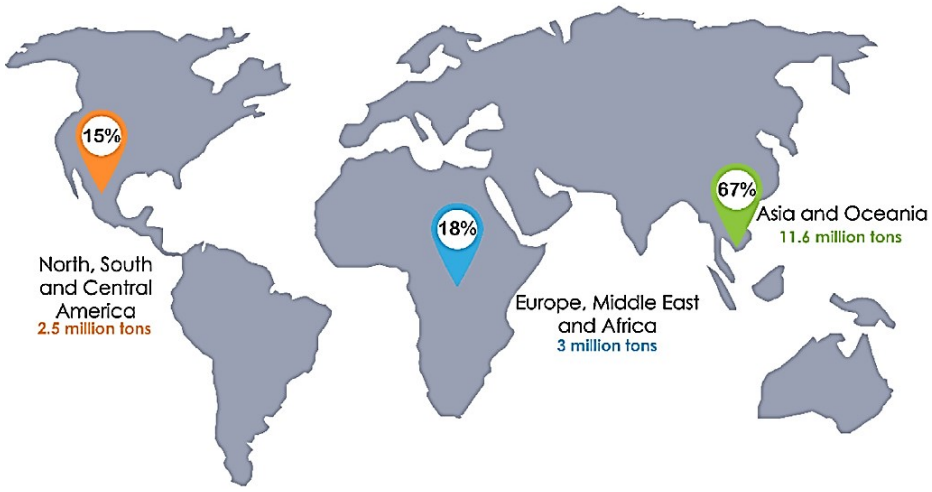

Figure 05. Worldwide Tire Production in percentage (%). (Araujo-Morera et al., 2021)

3. Literature Review and Gap identification

Tire industry is growing in a good pace, albeit in Covid19 pandemic time. Along with the growth of the industry by volume as well by market capital, the threat of disposing the End of Life Tires (ELT) are also growing rapidly (WBCSD, 2021). Many of the European countries are already having separate bodies or laws and regulations for ELT (Fig. 06) management, whereas, in the Asia-Pacific countries, the ELT norms are not so clear (Torretta et al., 2015). Fig 07 shows the ELT management by country/region worldwide. The categorization is as follows (a) EPR- Extended Producer Responsibility,

(b) Liberal system- Free market, (c) Tax System – Government responsibility, it is financed through tax.

Tire industry is working on 4R and the advanced 7R principles along with CE to achieve the sustainability targets (Fig. 01) (Zhongming et al., 2021), (Araujo-Morera et al., 2021). Sustainability reports of industry shows that tire majors already set a vison and target to achieve carbon neutrality and tires from 100% sustainable raw materials by 2050 (Bridgestone Corporation, 2021). World Business Council for Sustainable Development (WBCSD) and Tire Industry Project (TIP) has set Sustainable Development Goals (SDGs) for tire industry. The interim report of TIP is expected to be published by 2023 and the progress report by 2026, shall give an idea on how the TIP is able to achieve the targets fruitfully (Zhongming et al., 2020). In this project TIP, the majority of the tire majors are from European and American region and the participation from Asia-Pacific region is less.

Figure 06. ELT Management Bodies in European Region. (Torretta et al., 2015)

ELT management data by regions and countries shows that the total 28% of the materials are not getting recovered or getting unaccounted during the ELT process (Fig 07). Energy recovery is only 19% and a total of 51% material is recovered, which is getting used in tires as rubber crumbs, reclaim rubbers and in Civil Engineering as road and brick construction material (Araujo-Morera et al., 2021). Energy recovery in Asia-Pacific region is comparatively less to that of European and American region; 48% of America, 65% of European region. Considering the data of China, 53% of the materials are recovered and 47% of the materials are getting lad filled or not recovered. There is not enough data to substantiate the energy recovery from ELT of Chinese region.

A consolidated global ELT management, sustainable sourcing and material usage policies are not available. The scope of this study is to compare the Global tire manufacturing and consuming industries and its approach towards the sustainability move. This will enable the industry to realize and analyses

the gap in the current sustainable movement to achieve the target of tire produced from 100% sustainable materials by 2050 (Bridgestone Corporation, 2021).

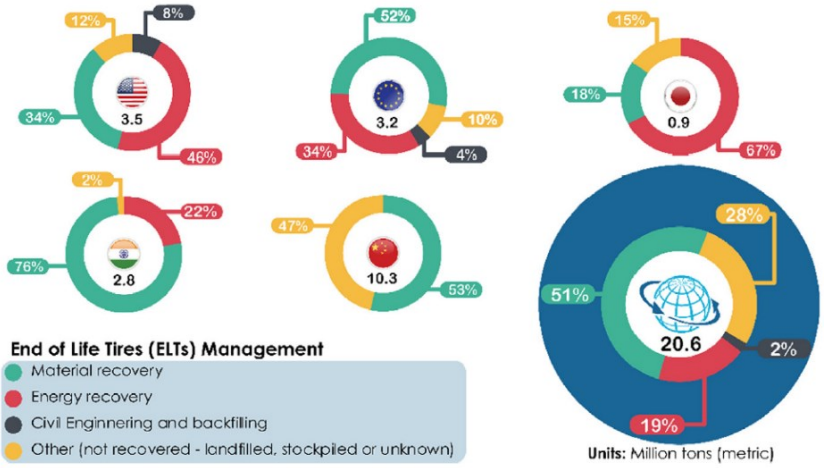

Figure 07. ELT Management by Country/Region. (Araujo-Morera et al., 2021)

4. Materials and Methods

To achieve and go beyond the targets set by the Tire industries and World Business Council for Sustainable Development (WBCSD), to be carbon neutral, make tires from 100% sustainable materials and use more of sustainable source of energy, the major approach is the 7R Circular Economy (CE) Model (Fig. 01) (Bridgestone Corporation, 2021), (Araujo-Morera et al., 2021). The current research focus on collecting and reviewing research papers from reliable data bases like Science Direct, Research Gate, Google Scholar, WBCS, TIP and sustainability reports of tire manufacturing majors worldwide like 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, BKT etc.

Tire industry raw materials can be classified mainly in to two; direct and indirect raw materials. All the raw materials which are directly consumed in the tire during the manufacturing process is considered as direct raw materials. All the raw materials which are not going in to the tire during the manufacturing process are considered as indirect raw materials. Further narrowing down the classification of raw materials we can see as follows

4.1 Polymers

Natural rubbers like Ribbed Smoked Sheet (RSS), Technically Specified Rubbers (TSR) are some of the examples of natural and sustainable polymer materials. Synthetic Rubbers like Styrene Butadiene Rubber (SBR), Poly butadiene Rubber (PBR), Ethylene Propylene Diene Monomer (EPDM), Isobutylene Isoprene Rubber (IIR) etc.

4.2 Rubber Fillers

Carbon black (CB) – carbon black is used to give strength to the rubber compound and increase and reinforce the polymer structure. This will improve the strength and physical properties of the rubber after vulcanizing or curing (Kumar and Nijasure, 1997).

Silica, it is one of the sustainable reinforcement filler used in tire industry for improving the tire performance (van Hoek et al., 2019). The advantage of this filler is that this can be used in black as well as colored compounds. Dispersion is one of the drawback of this filler. Tire industry is overcoming the dispersion issue by various process aids and usage of Silane-Coupling Agents (Sae-oui, Thepsuwan and Hatthapanit, 2004). Silica material produced from Rice Husk, which is sustainable and gets consumed by tire industries (Dominic et al., 2020).

Inorganic Oxides and Carbonates are another kind of fillers used in tire industry (Frazer, 2001). These are considered as non-reinforcing fillers, as it is not directly giving strength to the vulcanized rubber, rather, these materials are used to fill the voids and increase the volume and acts as a cheapener. Zinc Oxide (ZnO), Titanium Dioxide (TiO_2), Calcium Carbonates ($CaCO_3$), Aluminum Silicates (Al_2SiO_5), China Clay ($Al_2O_3(SiO_2)_2(H_2O)_2$) are some of the examples.

4.3 Reinforcing materials

Reinforcing Fabrics like Nylon 6 - $(C_6H_{11}NO)$ n, Nylon 6-6 - $(C_{12}H_{22}N_2O_2)$ n, Cotton, Poly (ethylene terephthalate) (PET), Aramid materials like Kevlar ($C_{14}H_{14}N_2O_4$) are the major fabric materials used in tire industry (Grishanov, 2011). In addition to this there are some new materials like NLP – Nylon Like Polyester is also used in tire industry.

Reinforcing Steel Tire Cord are the material getting made by wet and dry drawing processes (Korunović et al., 2019). This is getting used in the carcass structure of the tire as ply and breaker.

Bead Wire, is a metallic part of the tire structure coming in contact with the rim and is made by dry drawing process of metal wire.

4.4 Rubber Chemicals

Rubber Chemicals can be further classified in to master batch and final batch chemicals. Master batch Chemicals are used in the master batch mixing process. This can be in single of multi stage mixing, based on the product and process requirement. Anti-Oxidants, Anti-Ozonants, Process aids are some among the chemicals involved in the rubber compounding (Rodgers, 2016). Final Batch Chemicals are the chemicals involved in vulcanizing the rubber to impart chemical, physical and mechanical strength. Sulphur, accelerators and retarders are major in this category (Kumar and Nijasure, 1997).

4.5 Process Aids and Process Oils

These are mineral oils with different compositions which are used in the processing of rubber compounds in the process of compounding (Rodgers, 2016). Paraffinic Oils, Naphthenic Oils and

Aromatic oils are the few major types of materials used in industry (Öter et al., 2011). Eco-friendly oils are low PAH oils, like Distilled Aromatic Extract (DAE), Mild Extraction Solvates (MES), Treated Distilled Aromatic Extract (TDAE) are used in tire industry (Petchkaew, 2015). In addition to this, there are many metallic stearates are used as process aids in rubber mixing process.

Tire industry is currently using a wide variety of sustainable materials. Natural rubber is Polyisoprene (IUPAC name is (2-methyl but-1,3-diene) -) which is from Hevea Brasiliensis (Otten, Hein, Bondy and Faust, 2020). There are another natural sources of rubber, but the material output is not much as the Hevea rubber tree.

Guayule Rubber, a plant species named 'Parthenium argentatum' is extracted as latex and can be used as a replacement of synthetic as well as natural rubber (Sproul et al., 2020). This is a sustainable material, which can be cultivated in specific geographical regions of rocky and desert.

Another type of sustainable natural rubber latex producing plant is Russian Dandelion, the biological name of this material is Taraxacum kok-saghyz is also sustainable in nature (Collins-Silva et al., 2012).

Other major sustainable material in tire industry is the Regenerated Carbon Black (Bhadra et al., 2003), (Zhang et al., 2018). This is the carbon black, which is regenerated from the waste or used automobile tires. This can be used in place of regular carbon black as a full or a partial replacement based on the end product requirement.

Regenerated Polyester Tire Cord Fabric from waste PET bottles (Sulyman et al., 2018). This is the process of regeneration of Polyethylene Terephthalate (PET) from used and old bottles. Tire majors like Michelin has already initiated to regenerate and use tire cord fabrics like this.

Modified soybean oil (MSO), it is the oil synthesized from soybean oil, used in tire compounds as process oil (Xu et al., 2020). Orange oil, the oils derived from orange peels, are getting used in tire industry for special application like low rolling resistance (Flanigan et al., 2011). Further, biomaterial derived resins like pine tar, cashew derived resins, castor oil derived resins are used in tire industry to achieve specific requirements like traction and rolling resistance (Vleugels et al., 2013).

Rubber Crumb and Reclaimed Rubber are another major material used in tire compounding, which is treated and regenerated from ELT (Batayneh et al., 2008), (WBCSD, 2021). A wide range or rubber crumbs are used in tire compounds, with mesh sizes ranging from 40 to 140. Fine size crumb rubber is frequently used in bias 2-3 wheeler tires. This is used as rubber as well as a cost reducing agent with minimal degradation in physical, mechanical and dynamic properties. Reclaimed rubber substantially used as cost effective material in the tire industry (Rattanasom et al., 2005). Varieties of reclaimed rubber, which goes in tires are Whole Tire Reclaim (WTR), Super Fine Reclaim (SFR), High Tensile Reclaim (HTR) and Low Mooney Reclaim (LMR). The manufacturing process of rubber crumb and reclaimed rubber are from the old used end of life Tire (ELT). Initial process involves shredding of the

ELT and separation of the metal particle from it. Once the process is over, it undergoes the grinding process to get required mesh size of the particle. This is directly used as rubber crumb. On the other side, the manufacturing of reclaimed rubber involves the chemical breakdown and reclaiming procedure to make it to reclaimed rubber sheets (De et al., 2006).

5. Results and Discussions

Considering the review of tire major's sustainability reports and nation wise legislations and rules for ELT and sustainability, TIP progress report, and new development in sustainable raw material usage, the following are the major routes to achieve the targets and go-beyond.

(a) **Product Design.** The sustainability activities to be started from the product design stage itself, once the End of the Life (ELT) is reached, it can be redesigned to another use or extend the current usage. Re-grooving and retreading are some of the examples of this sustainable design of the ELT product. Also, reducing the mas and material usage to improve the durability characteristics of the tire is an another option, which is going in line with the sustainability move of tire industry.

(b) **Usage of Sustainable materials**. Tire industry is already using a variety of renewable materials like natural rubber, silica and may natural and plant derived oils, resins and filler materials. The development of silica from rice husk is evident of it. Castor oil derived oil usage in place of tire compound plasticizers, bio-resins, which are derived from plants used in place of petroleum origin resins. Many of the tire companies are already formulated the sustainable sourcing policies in line with WBCSD and TIP SDGs target (WBCSD, 2021).

(c) **Usage of Sustainable Energy**. Tire industry is moving towards reducing the energy dependency from the non-renewable energy sources (Markovska et al., 2009). Also they are in a move to reduce the total energy consumption. Further, zero water wastage plants are becoming predominant and the existing manufacturing facilities are converted to zero water wastage facilities. This will help industry to achieve the targets of sustainable energy consumption and reduced water usage and maximize the energy efficiency through mechanical inventions. These efforts will help to maintain the ground water level and a healthy ecological balance.

(d) **End of Life Tire management (ELT).** There are many models available globally to manage ELT. The major ELT management system are as follows (a) EPR- Extended Producer Responsibility, (b) Liberal system- Free market, (c) Tax System – Government responsibility, it is financed through tax (WBCSD, 2018), (Battista et al., 2021). Many of the ELT recovered products like rubber crumb, reclaimed rubber, tire derived fuel (TDF) can be used in tire industry directly as well as indirectly, like furnace oil and process oils (Pipilkaki et al., 2005). More researches are required to conclude and optimize the usage of TDF in the tire compounding.

(e) **Repairing of Tire – Retreading and Re-Grooving.** Retreading and Re-grooving are a common practice in tire industry (Markovska et al., 2006). It is trying to reinvent the new life

of the old used tire, which is supposed to get disposed after the ELT. By this process, the lifespan of the tire is getting extended. Retreading involves the process of application of the cured or vulcanized or uncured rubber on top of the treated tire carcass structure. Re-grooving involves the process of creating new grooves and design in the tire surface with the available rubber mass. Re-grooving of tires are majorly done in off the road tires (OTR) and solid tires, since the rubber mass on the surface of the tire carcass will be more in OTR and (Of the Highway) OHT tires.

(f) **Innovations**. Many of the tire manufacturing companies are coming up with many, out of the box innovations, which are redesigning the concept of the tire. Michelin Tweel, Hankook – I-flex, Toyo – No air, Bridgestone airless are some of the examples (Bras et al., 2011). These kind of inventions will change the product concept itself to provide improved durability and product life. This helps the industry to reduce the carbon footprint and reduce the material usage by increasing the product life cycle duration.

(g) **Indirect Material usage**. The materials which are not getting consumed directly in the tire manufacturing process are considered as indirect materials. Release materials and packaging materials are some of the examples. Some of the specific markets like Asian markets requires glittering covering for the tires individually, which is getting done with plastic materials which is not eco-friendly. Many European countries are moving towards packaging materials, which are sustainable and eco-friendly.

6. Conclusion

The present study of sustainable materials in tire industry covers a comparative analysis of the regions worldwide, focusing on Asia-pacific and European regions in the context of manufacturing and consumption of automobile tires. The current and expected growth rate, the present material usage pattern and the targeted sustainable material usage plan also been analysed. This analysis also discussing the Sustainable Development Goals by WBCSD and TIP, along with the Tire manufacturing majors sustainable vision for 2050 and beyond. The ELT management system of both European and Asia-Pacific regions are compared, by the methodology of ELT management, as recovery of material, energy and efficiency of the processes. The in-depth analysis of the different materials which are getting consumed in different tire segments shows the gaps and opportunities of sustainable material usage.

Asia-pacific regional countries are lacking in the ELT management systems, whereas the European countries are already having clear ELT management systems and bodies, which are taking care of the ELTs. Even though the ELT treatment efficiency in terms of material recovery for India and Asia regions are good, the energy recovery is yet to improve compared to European counterparts. China is one of the largest manufacturer as well as consumer of automobile tires, lacking in the data of energy recovery from ELT, which is a gap yet to be addressed. Also, the independence from non-sustainable energy sources and zero water policies of tire industries are taking more close to the sustainable targets

of 2050 and beyond. Sustainable materials to be continuously explored and developed in tire industry to achieve the target of manufacturing of tires from 100% sustainable materials.

The practice of circular economy (CE) based on 7Rs, starting from sustainable product design, material usage, energy usage reduction, ELT management and out of the box innovations can take the tire industry more close to the targets of 100% sustainable tire. More research and focus are required in Asia-Pacific region compared to European region in sustainability as system and legislations are weaker in Asia-Pacific region. This will help us to provides sustainable tire and mobility for the present as well as the future generation with the greener nature.

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