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Waste tyres accumulated in landfills: Environmental risk and mitigation strategies: A review

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Abstract
End-of-life tyres (ELTs) management is a growing environmental problem globally, caused by their complex material contents, non-biodegradable nature, and increasing abundance. Recycling, retreading, and energy recovery as sustainable management methods are promoted, yet a significant proportion of used tyres end up in landfills. This review examines environmental impacts of tyre rubber waste in landfill environments, considering in particular soil, ground, and atmospheric contamination, together with associated ecological and health risk consequences. Tyres are a combination of natural and synthetic rubber, carbon black, steel, various fibres, and an array of chemical additives that include heavy elements and organic chemicals. When disposed of in landfills, such wastes decompose slowly, providing leachates that are composed of extremely high levels of zinc, lead, cadmium, and other toxic materials that could be washed into nearby soil and groundwater. Further, tiny tyre pieces could contaminate soil and disrupt microbial communities, along with leachate flow, which could destroy nearby bodies of water. Another glaring fact is that tyres are a fire hazard when tyres are burned in a pile or buried as they lead to emission of toxic gases such as dioxins, furans, and volatile organic chemicals, causing air pollution as well as altering climate. Apart from devastating the environment, these pollutants directly and indirectly affect the health of people. They do so by polluting groundwater and by human beings inhaling dangerous smoke from burnt tyres. The current methods of managing such pollutants, such as unique landfill constructions and incorporation of tyre shredding in construction work, reduce it somewhat, yet don't eliminate the ultimate threat. This review suggests a need of better regulatory body for surveillance of landfill leachate, and adoption of circular economy strategies to reduce accumulation of tyres in landfill areas. The study is however unclear, specifically in regard to fates of micro-rubbers in soil as well as environmental outcomes from leachate transit through soil. More research targeting such knowledge gaps is a move towards sustainable approaches to tyre rubber waste management.

Keywords: Non-biodegradable, Landfill, Leachate, Circular economy, Micro-rubber

Introduction

Global tyre production and ELT generation

As per the comprehensive analysis performed by Osuagwu (2024) [52], world tire production has been registering gradual increase, with projected world production in 2023 at 2,388 million units. The Asia-Pacific region alone captures the greatest production, representing about 1,200 million units in 2022, primarily due to China, India, and Japan. Europe followed, having produced 423.6 million units, while in the respective year, North America produced 385.5 million units. The Middle East and Africa collectively contributed over 110 million units, registering steady although increasing demand. Figure 1 is the pie chart representation of the region wise tyre production. The outlook indicates that world tire production will remain in its positive incline, approaching almost 3,012 million by 2032, underpinned by rising vehicular ownership, innovation, and electric and hybrid vehicular conversions. Similarly, according to Mayer *et al*. (2024) [45], approximately 3 billion of tires are produces each year. The requirement of tyres for automotive is increasing worldwide due to the rise in number of vehicles. Torretta *et al*. (2015) [79] have mentioned that, recent tyre production in European Union (EU) was nearly about 334 million units per year. Similarly, In United States and China it was 300 million and 800 million units per year, respectively (USTMA, 2022 [80]; Dong *et al*. 2021 [17]).

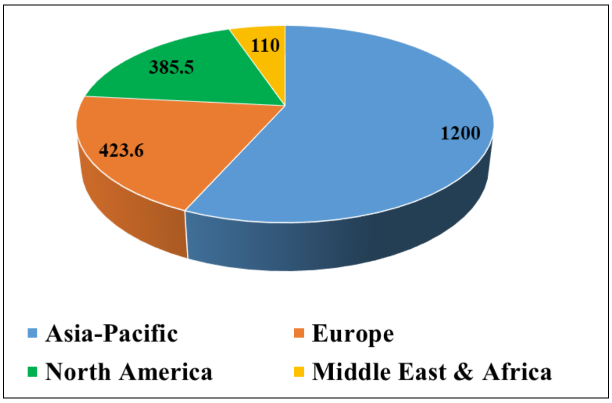

Fig 1: Region wise annual tyre production (in million units)

Jayanthi (2018) [31], stated that; India is one of the major player in tyre industry and holds fourth place in market size with the consumption of over 184 million units in 2018. The production of new tyres has been increased from 152 (2015-16) million to 217 (2022-23) million units (Malik, 2024 [43]). On contrary, each and every tyre has a life cycle, after that it becomes waste and needed to be recycled or proper management strategy to dispose. Globally, almost 1.5 billion tyres at end-of-life are generated every year with an annual increment rate of 4.3%, producing more than 13 million tonnes of ELTs, much of it being landfilled or burned, posing extreme environmental harm (Shivaji, 2019 [67]; Thiyagarajan & Thenmozhi 2012 [76]). India contributes around 6% of global waste tyres, which is over 100 million annually out of 1.6 billion waste tyre generated globally (Sathe *et al*. 2020 [64]; Bansal and Kapgate, 2023 [9]; Auti *et al*. 2020 [7]). Almost 275,000 tyres are disposed per day in India, in addition to importing 300,000 tonnes every year for recycling (Bansal and Kapgate, 2023 [9]). Waste tyres are non-biodegradable in nature, bulked tyres often create fire hazards, leachate can create soil and water pollution, breeding of various disease vectors (Moasas *et al*. 2022 [46]). Despite improvements in retreading, pyrolysis, and recycling, global country recovery is still below 40%, and mountain-like stocks of tyres continue to go uncontrolled (Shivaji, 2019 [67]). This highlights the importance of sustainable practices and circular economies in litter management of tyres.

Disposal of waste tyres

Therefore, proper management and disposal techniques for ELTs are prerequisite of the present trend. As per the review conducted by Rowhani and Rainey (2016) [61] the management of scrap tyre is usually done by landfilling, gasification, retreading, recycling and pyrolysis. The scrap tyres are also processed in the form of ground rubber crumb using mechanical or cryogenic processes (Xiao *et al*. 2022 [83]). Besides that, scrap tyres (mostly in crumb form) are also used in construction industries for making asphalt, artificial turf, paver blocks and as elastic aggregate in cement concrete mixture (Joohari and Giustozzi, 2022 [32]; Mohajerani *et al*. 2022 [47]). The most common methods of disposal of waste tyres are dumping in landfills and pyrolysis (Khan *et al*., 2024 [34]; Afash *et al*. 2023) [3]. But still most of the developing countries have adopted landfill as the suitable option for disposing waste tyres as the cost of process is very low as compared to other complex methods (Ferdous *et al*. 2021 [21]; Asaro *et al*. 2018 [6]). Figure 2 exhibits the most frequently used disposal techniques for ELTs (Afash *et al*. 2023 [3]; Abadi *et al*. 2022 [1]; Soprych *et al*. 2023 [71]).

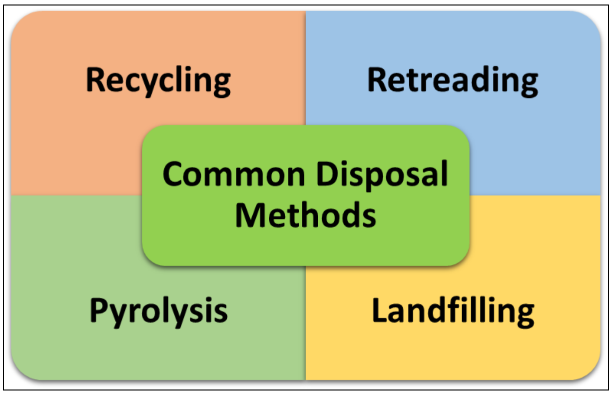

Fig 2: Common pathways for disposal of ELTs

The dumping grounds are stockpiled with scrap tyres, these stocks can act as a potential fire hazards if somehow ignited and may impart significant health and environmental harm (Smith, 1999 [70]; Adhikari *et al*., 2000) [2]. Waste tyre into landfills leaches out toxic chemicals along with heavy metals due to weathering and under varying pH conditions. Which can contaminate soil, ground water and ultimately the crops as well (Duda *et al*. 2020 [19]; Rigotti and Dorigato, 2022 [59]). The main objective of this review is to highlight the environmental impact of waste tyres disposed of in landfills. It clarifies that, how the chemicals present can contaminate the soil, water, and air. In addition to that, clearly states about the potential health hazards to humans and livestock. Leaching of heavy metals, small rubber particles spreading around, and even fires starting up. The whole thing covers what's in tyres, how the pollution spreads, and ways to fix it, like recycling or burning them for energy. This investigation points out where research is missing some pieces. Basically, we need better ways to handle this stuff in a circular economy setup. That way, things don't just pile up forever.

Methodology

The present study was conducted through extensive literature survey to find out the problems and mitigation measures as well as the research gap. Total 215 research and review papers were studied. Out of 215 documented research articles total 85 articles were included in this review paper based on their relevance and connection with the topic. All 85 articles were deeply reviewed to extract their key insights and valuable information whichever was beneficial for this review article. Figure 3 exhibits the flow chart of the work carried out. Science Direct, Web of Science and Google Scholar database was used to search original piece of research and review articles.

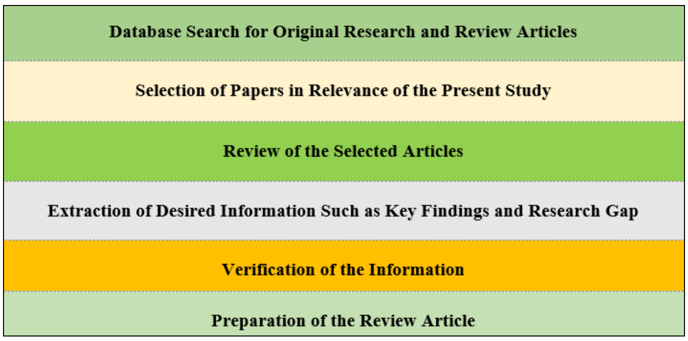

Fig 3: Step by step review process adopted

Composition of tyre rubber

Generally tyres are classified broadly under two categories: car and truck tyres. Both are different from each other in terms of their chemical composition of the concentration of the constituent materials (Ganjian *et al*. 2009 [24]). Table 1 below shows the chemical composition of light passenger vehicle and truck tyres. It clarifies that, main difference is in the concentration of natural and synthetic rubber, steel as well as fabric reinforcement.

Table 1: Composition of light passenger vehicle and truck tyre (Svoboda *et al*. 2018 [73]; Li *et al*. 2004 [39])

Constituents	Amount in Percentage (%)	
	Light Passenger Vehicle	Truck
Natural Rubber	19	34
Synthetic Rubber	24	11
Filler	26	24
Steel	12	21
Antioxidants, Antiozonants and Curing System	14	10
Fabric	4	Nil

The common construction of light automotive tyres is given in Table 2.

Table 2: Chemical constituents in car tyre rubber (Gursel *et al*., 2018 [27]; Rouse, 2005 [60])

Constituents	Mass Percentage
Rubber	48
Carbon black and silica	22
Metal reinforcements	15
Oil, deterioration inhibitor, wax, stearic acid, etc.	8
Fabric	5
(ZnO)	1
Curing agents	1

Tires may have plenty of chemicals, mostly those which are added during the manufacturing process in the form of additives, such as N-(1,3-dimethylbutyl)-N-phenyl-p-phenylenediamine, chemical contaminants like polycyclic aromatic hydrocarbons (PAHs), and the chemicals formed with ageing of the tyre rubber due to UV-weathering (Tian *et al*., 2021 [78]; Kovochich *et al*., 2021 [36]). The Additives which are frequently used in tyre manufacturing are Thiazoles, Thiurams, Sulfenamides, and Guanidines (2-Mercaptobenzothiazole, N-Cyclohexyl-2-benzothiazolesulfenamide, 1, 3-Diphenylguanidine), which can enhance the chemical reaction and improves the characteristics of tyre manufactured. Antioxidant such as p-phenylenediamine is used to increase the storage and service lives of tyre rubber. Processing additives are dispersants, homogenizers, plasticizers, heavy metals and coupling agents, which can improve product quality and enhance efficiency in production, such as dibutyl phthalate and Hexamethoxymethylmelamine (Rauert *et al*., 2022 [57], Ni *et al*., 2008 [50], Wik and Dave, 2009 [81], Kim and Kim, 2013 [35]). These additives are used to improve the characteristics of tyre but they are significantly toxic for the soil and water ecosystem if leaches through the landfilled tyre rubber (Zhang *et al*., 2023 [85]). Due to the addition of protective chemicals the normal rubber becomes non-biodegradable in nature.

Therefore, management of ELTs are the most important concern towards the environment due to their non-biodegradable nature (Magagula *et al*., 2023 [42]). Tyres are highly resistant to degradation that is why their disposal is a problem which needed to be addressed (Pasalkar, *et al*. 2015 [53]).

Environmental impact of tyres dumped in landfill sites

The consequence of improper disposal is deep: waste tyre rubber happens to be a threat to air, water, and soil quality through the processes of weathering and leaching of contaminants. In that regard, Zainol *et al*. (2022) [84], Roy *et al*. (1999) [62], Li *et al*. (2010) [40], and Han *et al*. (2023) found that the scale of the problem due to waste tyres worldwide is just breath-taking, and millions of ELTs discarded every year. Although recycling and re-treading facilities are available, only 100 million tyres are recycled by recycling industries in a year (Senthil & Thenmozhi 2012 [65]). The rest of the used tyres are either sent to landfills, or else they are treated in energy-consuming thermal degradation process which has the likelihood of creating a large amount of pollution if environmental standards are not met (Goevert 2023 [26]; Downard *et al*. 2015 [18]; Singh *et al*. 2015 [68]).

Leachate Contamination to Soil, Water and Crops

Open dumping plastic and tyre wastes lead to contamination of soil and water bodies through processes such as weathering and leaching. These materials could possibly contain leachates of complex mixtures of toxic chemicals in landfills that seep into soil and groundwater. These include heavy metals such as lead, cadmium, and mercury, as well as persistent organic pollutants such as polycyclic aromatic hydrocarbons, phthalates, among many others, that can bio-accumulate in animals that will eventually find their way to the food chain through agricultural crops and livestock, ultimately risk human health (CPCB, 2015 [13]; Czajczynska *et al*., 2020 [14]). Heavy metals like cadmium, lead, arsenic, mercury, and chromium are potential environmental pollutants. Whenever these contaminants accumulate to toxic levels in agricultural soils, the productivity and crop health is adversely affected (Rashid *et al*., 2023 [56]). At the micro-molecular level, contamination due to heavy metal decreases the crop productivity by generating reactive oxygen, which disturbs the redox balance and causes oxidative stress in crop system. Soil contamination with so-called heavy metals (HMs) has been a great issue of concern owing to enhanced bioavailability and HM accumulation in food crop plants (Shahid *et al*. 2015 [66]). Soil contamination by heavy metals (HMs) has become large issue as a result of enhanced bioavailability and accumulation of HMs in food crops harvested from contaminated fields. One of the major source of heavy metal contamination to the soil is tyre dumping yards, it supplies HMs to the nearby water bodied and soil system (Hamoud *et al*. 2024 [28]). In addition to this, the physical accumulation of abandoned tyres in the environment changes soil characteristics, and interrupts the natural drainage within an ecosystem. Micro debris from the piles of tyres recharges the soil chemically, which may impact the development in plants (Leifheit *et al*., 2022 [37]). Lastly, this types of ecological disturbances do not go unnoticed because they have impacts in changing the behaviour of the biodiversity at the specific site of the landfill. Numerous studies have confirmed the deleterious impact of leachate oozes out from landfills on soil well-being because the leachates are overloaded with elements like nutrients, soluble salts and heavy metals which is harmful for soil microstructure and ultimately for agricultural and plant ecosystem (Naveen *et al*. 2017 [49]; Arunbabu *et al*. 2017 [5]). According to Junqing *et al*. (2020) [33] review, waste tyres are one of the most critical environmental problems worldwide and are pollution in air, water and soil. In addition to that, aquatic environments are more vulnerable, plastic and tyre debris can leach in to the aquatic environment along with rain water of and remain there for hundreds of years, posing entanglement risks on aquatic life and changing food webs (Tekman *et al*., 2022 [75]; Thushari & Senevirathna, 2020 [77]).

Environmental Pollution and Health Hazard

Recognizing these dangers, the European Landfill Directive (EU, 1999 [20]) has banned the disposal of waste tyres in landfills since 1999. In doing so, the regulation reflects a clear need for increased safer ways of managing waste tyres than making short-term economic profits. Dumping sites are associated with the high risk of getting ignited, fire hazards can cause serious environmental pollution and human health risk (Malinauskaite *et al*., 2017 [44]; Mohajerani *et al*., 2020 [47]). In addition to this, burning the rubber waste in the absence of adequate control over pollution will add further to the contamination since it also contributes to the release of greenhouse gas. The emissions from this outcome not only accelerate climate change but also underscore the necessity for more responsible tyre-waste management strategies by evading uncontrolled fires and reducing the danger of pollution (Ghorai *et al*., 2019 [25]). The end-of-life tyres can readily fill any dumping area due to its high growth rate, a critical extreme fire hazard owing to the fact that rubber is a highly volatile if ignited. The grazing fire caught by stockpiled tyres may sustain for an excessively long time (Mohajerani *et al*., 2020 [47]). Such fires are very hard to be put out. One example is the case of a wildfire that happened in 2012 at the local landfill site in Iowa City, Iowa, USA, where a fire continued to burn for 18 days as it was not controlled. The site had reached the inventory level of around 20.5 million kilograms of tyres, and the fire emitted high amounts of hazardous air pollutants. The overall pollutants included carbon dioxide, sulphur dioxide, fine particulate matter (PM2.5), and polycyclic aromatic hydrocarbons (PAHs) were all harmful to the human body (toxic breathing air) and the environment (Downard *et al*., 2015 [18]; Singh *et al*., 2015 [68]). In another similar kind of study, Zainol *et al*. (2022) [84] quoted that, waste tyres harm the environment as a result of incorrect disposal, causing a global environmental disaster. The quantity of rubber tyre waste piles continues to rise, bringing new environmental, safety, and aesthetic concerns due to a lack of obvious disposal solutions (Magagula *et al*., 2023 [42]).

In spite of that, the majority of waste tyres, approximately 50%, is left in the landfill without any kind of preliminary treatment. This improper waste management worsens environmental degradation, thereby pushing forward the demand to adopt a more sustainable solution in tyre waste management (Formela *et al*., 2021 [23]) and related pollution risks. Similarly piles of waste tyres can accumulate water and can become stagnant breeding sites for mosquito vectors of the disease and hence increase the risk of vector-borne diseases such as malaria and dengue fever in affected areas (Fiksel *et al*., 2010 [22]). However, despite this aspect, landfilling of whole or shredded tyres is likely to be the cheapest method of waste disposal, which carries high environmental and public health risks, thus making it an unacceptable waste management practice (Zainol *et al*., 2022 [84]).

Mitigation Strategies Through Recycling and Energy Recovery

The environmental challenges arises due to the faulty disposal of waste tyres needed to be addressed. The present management practices should be improved or reorganized in the form of alternative solutions. The improper practices should be replaced with excellent management and mitigation strategies with respect to the recycling of discarded tyres. The need on this hour is to control this alarming issue in an economically viable and environmental friendly manner. Government of India has made extended producer's responsibility (EPR) principles to regulate the waste tyre management strategies. Khan *et al*. (2024) [34], observed that, around 50% of tyre pyrolysis plants are non-compliant with government (EPR) policies and are in need of upgrade in their process through the adoption of modern technologies. Several units of waste tyre pyrolysis were ranked in red, green, and orange categories based on their pollution level and as a consequence a number of plants were closed. Symeonides *et al*. (2019) [74] documented that, the prominent treatment technologies applied in Cyprus are the utilization of ELTs to make rubber granules which is used as an alternative energy source in cement plants (609-2738 tonnes/year), to cover artificial surfaces or base material to construct artificial lawn pitches and for pyrolysis (324-837 tonnes/year). One of the less recommended but economic way of waste tyre disposal is landfills, approximately over 4 billion waste tyres were stock piled into different dumping yards in the world (Christensen, 2011 [10]). Another researcher Banerjee, (2019) [8] described tyre retreading technology in his book and explained it as tyre recycling technology, heavy of light passenger vehicles need repairing on the tyre after certain time. The worn-out tyres are repaired as new, but this technology has some limitations because not applicable on all kind of tyres. As the heating value of tyre derived fuel is greater in comparison to coal, it is very well adapted to be utilised as a fuel in several combustion applications like cement kilns and boilers. Compared to combustion of coal, combustion of tyre derived fuel is less harmful to the environment due to reduced emissions (Conesa *et al*. 2008 [11]). Shredded or ground tyre tuber (GTR) may be co-combusted with coal for various industrial sectors like power generation by enhancing thermal efficiency of boiler and furnace (Singh *et al*. 2009 [69]; Levendis *et al*. 1996 [38]; Courtemanche and Levendis, 1998 [12]). Similarly, another conventional method of tyre recycling is to disintegrate the scrap tyres into smaller particles through mechanical and cryogenic grinding method, these particles may further be used for combustion, construction and rubber reclamation (Sunthonpagasit and Duffey, 2004 [72]; Reznik, 2002 [58]; Liang and Hao, 2000 [41]). The rubber industry was initially completely reliant on natural rubber, a commodity which was limited in supply and expensive. The inadequacy of most of the natural rubber material promoted the use of alternative synthetic rubbers and recovery methods for reclamation of rubber from scrap. Recycling end-of-life tyres, tubes, and other rubber articles through reclaiming processes emerged as significant means of waste management as well as conservation of resources. Besides addressing the issue of scrap tyre disposal, rubber recovery minimizes dependence on crude petroleum raw materials.

In addition to the above, Gasification is the thermochemical decomposition process of waste tyre rubber into various by products (Syngas, char and water) at elevated temperatures (800-1000°C) and partial pressure. Syngas is mainly utilised for as fuel for gas turbines to generate electricity (Nikrityuk and Meyer, 2014 [51]; Raman *et al*. 1981 [55]). Pyrolysis is a thermochemical process of conversion of organic materials into low-molecular weight products by decomposition under high temperatures, usually ranging between 400 °C and 1000 °C, without oxygen. This condition necessitates drying of the feedstock before processing in order to eliminate the interference caused by moisture. The process name has its origin in the Greek words pyro (heat) and lysis (breakdown), meaning the thermal cracking and depolymerisation reactions involved. Pyrolysis has been utilized historically to produce charcoal for more than 5000 years (Antel and Gronil, 2003 [4]). The properties of pyrolysis product and yield mainly rely on the quality of feedstock, heating rate and reactor conditions. Pyrolysis has been adopted for waste treatment due to its potential to process ELTs into high-value products such as bio-oil, syngas, and carbon black. Tyre pyrolysis is environmentally beneficial due to lower emissions, barring less leakages from equipment (Demirbas, 2007 [16]; Williams and Bottrill, 1995 [82]). The multicomponent polymer matrix of tyres starts to decay around 350 °C, as sulphur bonds are the first to deteriorate because of having a lower dissociation energy than C-C and C-S bonds (Dean, 2007 [15]). Different reactor geometries, such as fixed-bed, fluidised-bed, rotary kiln, screw kiln, and vacuum systems, have been investigated for tyre pyrolysis, with the fixed-bed reactor most commonly used (Hita *et al*. 2016 [30]). Temperature, residence time, pressure, and carrier gas atmosphere are still the prevailing parameters that impact yields and product distributions (Quek and Balasubramanian, 2009 [54]).

Research Gap

While the global tyre production patterns and generation of ELTs have extensively been addressed (Osuagwu, 2024[52]; Mayer *et al*., 2024[45]), there are certain fundamental knowledge gaps regarding their long term environmental impacts and sustainable management. A lot of existing literature is based on the level of production, treatment of waste, and technical recovery processes like retreading, pyrolysis, and recycling. But global recovery rates are below 40%, and even millions of tonnes of ELTs clogging the landfill areas (Shivaji, 2019 [67]). It is an imbalance of technological potential and its extensive application. Environmental analyses are likely to highlight short-term risks such as fire, leachate pollution, and breeding of disease vectors (Duda *et al*., 2020 [19]; Rigotti & Dorigato, 2022 [59]), while large amounts of information on long-term ecological effects of micro-rubbers derived from tyres and long-term interactions with aquatic and terrestrial environments are limited. Furthermore, the majority of the research has been carried out in industrialized countries, where policy interventions such as the EU landfill ban have encouraged innovation. Conversely, cheap landfilling continues to dominate in the developing nations, but there is scant site specific risk evaluation, pollutant pathway monitoring, and evaluation of local socio-economic barriers to sustainable alternatives (Asaro *et al*., 2018 [6]; Ferdous *et al*., 2021 [21]). There is also another general area of research with regard to life-cycle analysis of tyre management practices. Pyrolysis and cement co-processing are highlighted as potential options. Therefore, studies are required in energy recovery, emissions, and circularity in a wider sustainability context. Similarly, there is limited research concerning the economics of mass deployment of innovative recycling technologies, given uncertainty over the regulatory and market environment. In relation to that, research is required to monitor the impact of leachates, micronized tyre rubber and thermal degradation residues on soil and water bodies as well as nearby agricultural fields and crops.

Future Directions

Closing these loopholes needs an inter-disciplinary effort synthesizing environmental science, engineering, economics, and policy. Future research needs to focus on:

a) Extended duration monitoring of landfill facilities to measure leachate makeup, micro-rubber mobility, and their eco-toxicological effects on soil, water bodies and agricultural crops.
b) Life cycle assessments (LCA) of the recovery and disposal routes to compare their environmental trade-offs on a regional basis.
c) Socio-economic and regulatory studies in developing nations to identify barriers for adoption of sustainable practices and develop regionally sustainable solutions.
d) Circular economy models, like extended producer responsibility (EPR) systems, to shift from linear disposal to resource recovery.
e) Technological innovation in pyrolysis, gasification, and material recovery for improvement in recoveries, lowering emissions, and reducing the cost of operation.
f) More research required towards human health, mainly due to the toxic fumes from blazing tyre and polluted water due to leachates.

Conclusion

End-of-life tyres (ELTs) remain a significant global concern, largely due to their stubbornly non-biodegradable nature and complex chemical composition—not to mention the ever-increasing piles from skyrocketing vehicle numbers. While approaches like recycling, retreading, and pyrolysis have shown some promise for resource recovery, the reality paints a less optimistic picture: a hefty proportion of waste tyres still wind up in landfills, bringing persistent environmental and public health risks. These tyres not only leach heavy metals and toxic organic compounds, but also contribute to micro-rubber pollution and, at times, can ignite uncontrollable fires. Together, these impacts undermine soil quality, contaminate groundwater, foul the air, and ultimately threaten both human and ecosystem health. Sure, there have been technological advancements in tyre recycling, but on a global scale, recycling rates continue to lag at under 40%. That gap between innovation and widespread adoption remains glaringly obvious. Moreover, current studies most often focus on short-term hazards, and long-term environmental interactions, especially the destiny of micro-rubbers and leachates within terrestrial and aquatic environments, are not well understood. Such a gap is extended even further in developing countries, where landfilling remains the most preferred method to date, owing to economic reasons despite its hefty environmental cost. Sustainable ELT management simply can't thrive when isolated; it fundamentally requires multidimensional collaboration and input from a range of disciplines. Frankly, unless we genuinely implement circular economy principles and hold producers accountable for the full lifecycle of their products, tire waste is just going to keep piling up. Solid policies need to be informed by thorough lifecycle analyses not just surface-level intentions. Real progress requires coordinated action; otherwise, any ambitions to divert tires from landfills are just empty optimism. At the same time, though, tailoring solutions to fit specific regional realities remains equally important one size fits all approaches just don't cut it. Effective, collective efforts don't just mitigate environmental harm; they also transform waste tyres into useful resources that genuinely support broader agendas in sustainability and climate resilience.

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