Global ELT Management – A global state of knowledge on regulation, management systems, impacts of recovery and technologies

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Executive summary

Deloitte was commissioned by the World Business Council for Sustainable Development (WBCSD) in the context of the Tire Industry Project to conduct a study on end-of-life tire (ELT) management and prepare the present report. This report has been submitted and published by WBCSD. This present study provides an update to the State of Knowledge (SOK) in a selection of countries (Part I) from the previous WBCSD ELT study conducted between 2016 and 2017 but also delves deeper into aspects such as studies conducted on the impacts of recovery methods, products, applications on human health and the environment, and research and development of advanced ELT recovery technologies. In addition, the report also analyses the feasibility of different major ELT recovery categories (Part II) through the associated methods, products and applications according to a number of criteria covering regulatory context, technical feasibility, economic drivers, and sustainability considerations.

The results of the study presented in this report are based on information collected via literature review and interviews with a variety of different stakeholders. The quantitative data on ELT management presented in this study needs to be interpreted in relation with the methodological assumptions and limitations. We would like to thank all of those who kindly participated in the study, through interviews or by other means, supporting the completion of this project.

The purpose of **Part I**, the SOK, is to provide an overview of the current ELT management systems for a selection of 45 countries: Argentina, Brazil, China, Europe (Throughout the report the scope for the region includes countries covered by ETRMA - European Tyre & Rubber Manufacturers' Association), India, Indonesia, Japan, Mexico, Nigeria, Russia, South Africa, South Korea, Thailand, and USA which cover 83.5% of vehicles in use in the world (Source: OICA, [International Organization of Motor Vehicle Manufacturers], 2015 data. Including the countries from the 2016-17 WBCSD TIP ELT study as shown in Figure 3, the coverage rate reaches 89%). In relation to the last study, the scope of this report focuses on countries identified as having well-established ELT management systems (including data availability), countries with particularly interesting dynamics regarding growth in recovery methods, products and applications markets, and countries that have significant potential for development in this domain. Nigeria was added to the scope due to its significant contribution to the number of vehicles in use and for the potential for development of a formal ELT management system and ELT markets in the country.

Different ELT management systems exist and there is no 'one size fits all' approach to a successful system. Extended Producer Responsibility (EPR) systems or take-back obligation system, government responsibility financed through a tax, and free market systems make up the management systems identified during the SOK. In practice, hybrid systems can be implemented and other variants of these systems also exist. Overall, some form of intervention and policy measure from the government is usually necessary in order to properly develop the ELT recovery industry. Transportation generally represents an important cost factor especially when collection points are not accessible or if infrastructure is insufficient. That can constitute a barrier in some countries that have a free market system. Therefore, in countries where an eco-fee is collected, a significant part of it is usually allocated to cover the transportation fees.

Based on the results from the current SOK, the total amount of ELT recovered (including ELT collected in China with undetermined end use) in the 13 countries and the region of Europe (as listed above) is estimated to be around 26 million metric tons (57 billion lbs) per year, while the amount of ELT generated is estimated to be around 29 million metric tons (64 billion lbs). The countries and regions that recover the largest quantities of ELT are China, United States and Europe. China is considered to have the highest recovery rate, of 100%, although just under two thirds are not formally registered and are deemed to be ELT collected with undetermined end use. Meanwhile, the management system in Brazil was reported as just short of full recovery (99.8%), in relation to targets based on generation, through EPR. Finally, India follows closely (98%) with a significant portion also informally recovered.

The technologies selected for evaluation in **Part II** were identified as major global categories during the extensive SOK review of ELT management around the world. The scope of this Part II includes: cement kilns and other energy production (e.g. power plants and boilers), civil engineering (e.g. barriers and embankments), granulation (e.g. rubber-modified asphalt, artificial turf infill, playgrounds, molded rubber products), pyrolysis, reclamation and steel production. As in the last study, the main ways to recover ELT have been grouped into the following categories: material recovery, energy recovery and civil engineering and backfilling.

Overall, the majority of the ELT generated (in metric tons) in the countries/regions included in the present study combined with the additional countries from the 2016-17 WBCSD TIP ELT study are distributed to forms of recovery with a determined end use including **material recovery** (42% of ELT generated) and **energy recovery** (15% of ELT generated) with a small portion directed to civil engineering and backfilling (2% of ELT generated) (see world map on page 21). Although the two recovery sub-categories, tire-derived fuel (TDF) and tire-derived material (TDM), are rather well spread at the global level and used as the main recovery routes in a large number of countries, the production of reclaim rubber is mainly developed in Asian countries: China, Japan and Thailand. Reclaim rubber is the main confirmed recovery route in China (34% of the total domestic recovery market) that represents close to one fifth of the total ELT recovered (including civil engineering and backfilling) for the selected scope. Reclaim rubber is mainly used in rubber-molded products and has been used in new tire manufacturing, albeit generally in only small quantities.

Forms of material recycling to obtain products with value and a significant lifespan stand out in particular in terms of overall feasibility. For example, although the production of rubber granulates and powder can require higher process costs as well as demanding efforts to create new partnerships with other secondary end-user industries, it also generates products with greater added value and has better environmental performance in terms of resource saving and emissions reduction.

Some regions or countries have set objectives to encourage recycling and limit other forms of recovery, while others have established more stringent **regulation** to exclude energy recovery from ELT management systems. Setting up grant programs is also common in some areas, such as North America, where subsidies are given for the use of rubber granulate in high value applications, promoting material recycling.

Energy recovery can be a particularly efficient way to deal with high volumes of ELT and eliminate long-standing stockpiles because it is generally technically straightforward to implement and can be deployed on a large scale to achieve relatively quick pay-back for the initial investment. The use of ELT as an alternative fuel is also encouraged to reduce CO2 emissions. Nevertheless, as a general trend, once a country has established a more mature approach to ELT management, material recovery is often supported through policy-making prioritizing recycling over other forms of recovery, such as energy recovery, following a waste hierarchy (prevent, reuse, recycle, recover, dispose). Indeed, energy recovery may be constrained by regulatory context aligned with the waste hierarchy, and the compliance with or promotion of such waste management hierarchies is common in many of the regulatory frameworks assessed in this study. However, other more indirect policies in the context of energy transition such as greenhouse gas emission (GHG) reductions and energy security can be responded to through use of ELT as an alternative fuel, with a high calorific value, renewable energy component and reduced carbon intensity relative to fossil fuels such as coal.

From a **technical feasibility** standpoint, various recovery routes are capable of treating significant volumes. For instance, cement kilns can absorb large amounts of ELT without significant technical difficulties. However, as capital investment is necessary for adaptation, a long-term perspective is required. Civil engineering applications on the other hand do not require the same level of initial investment but have relatively high capacities. Despite the currently limited market, civil engineering may have considerable potential. Meanwhile, TDM obtained through granulation is overall a straightforward well-established process with particularly advantageous properties and performance for applications such as rubberized asphalt.

Enabling both material recovery and energy recovery, the cement industry, with significant capacity, remains an important hybrid destination for ELT provided that a number of **economic criteria** are met, including traditional fuel costs remaining high in comparison and the availability of gate fees as an additional incentive.

For the collection and delivery tied to the cement industry, for instance, this was as simple as the retraction of gate fees provided through extending producer responsibility financial transactions.

Meanwhile, business profitability depends on the price of the TDF or TDM. The economic assessment of ELT recovery routes must make a distinction between those that depend on the added value of output products using ELT as feedstock (material recycling in particular), and those that replace traditional materials or fuel with ELT. The economic model for several granulation applications may require relatively high investment costs for equipment and infrastructure, while the economic viability of other applications will depend on the price of the traditional counterpart (e.g. fuel). The competitiveness of TDF or TDM is directly affected by the prices of competing products and materials.

The **sustainability** considerations relative to ELT recovery routes can be assessed through their environmental performance in particular. Some recovery routes have considerable benefits in terms of avoided impacts according to several life cycle analysis/assessment (LCA) studies, such as the use of ELT in cement kilns and in artificial turf infill. Seizing the importance of this issue, new technologies are placing a lot of focus on mitigating negative impacts and enhancing efficiency, with reductions in energy and water consumption for example. The impact of these technologies on human health must also be considered, and a wide array of studies have been conducted on those that are considered of potential risk. Nevertheless, public and industry perception play a crucial role in the acceptance of these technologies, and therefore in the further development and expansion of recovery routes.

Finally, the major factors differentiating the feasibility of ELT recovery technologies in countries with developing or non-existing ELT management systems when compared with those with mature ELT management systems are directly related to governance and infrastructure. Where little framework exists, the stages of the supply chain lack synergy and consequently the case for investment in large scale facilities is harder to make.

Glossary of terms used

Cement and other energy production: Recovery methods by which ELT are used as tire-derived fuel (TDF) in energy intensive industries such as cement kilns, power plants and industrial boilers. In the case of cement kilns both energy and material recovery occurs in the process.

Civil engineering and backfilling: Recovery route where ELT are recovered through civil engineering applications (water retention and infiltration basins, supporting walls, etc.) and through landfilling of mining activities (tires that are shredded and mixed in with other geological materials to reclaim sites that have been mined out for example).

Devulcanization: Chemical process by which bonds of vulcanized rubber are broken without shortening the carbon chains. Devulcanization is a recovery method for material recovery.

Devulcanized rubber: Rubber produced from the devulcanization process.

End-of-Life Tire or End-of-Life Tires (ELT): A tire that can no longer serve its original purpose on a vehicle. This excludes tires that are retreaded, reused, or exported in used cars.

End-of-life vehicle (ELV): A vehicle that can no longer serve its original purpose.

Energy recovery: Recovery category where ELT are recovered as tire-derived fuel (TDF). For the purpose of this study, it was considered that 75% of ELT used in cement kilns are recovered as energy. For ELT that are recovered through unknown means of recovery, a 50/50 split has been made between energy recovery and material recovery except for China where material recovery is favored.

Extended Producer Responsibility (EPR): In the case of ELT, the producer of tires (manufacturer or importer) is held responsible by law to organize the ELT management, with targeted volumes generally defined based on the quantities of tires put onto market.

Gate fee (or tipping fee): The price levied on the entity delivering ELT to a landfill or to a recovery or a recycling facility.

Granulation: Recovery method which involves the breaking down of ELT into smaller particles through different processes to obtain rubber granulate and powder, used in multiple applications.

Hybrid recovery route: ELT recovery routes which lead to both energy and material recovery (e.g. use of ELT in cement kilns).

Material recovery: Recovery route category where ELT are recovered as a new material. It can be used to produce tire-derived material (TDM) for instance. For the purpose of this study, it was considered that 25% of ELT used in cement kilns are recovered as material. For ELT that are recovered through unknown means of recovery, a 50/50 split has been made between energy recovery and material recovery except for China where material recovery is favored.

Off–the-road tires (OTR tires): Tires used on large vehicles that are capable of driving on unpaved roads or rough terrain. Vehicles include tractors, forklifts, cranes, bulldozers, earthmoving equipment, etc.

OICA, International Organization of Motor Vehicle Manufacturers (Organisation Internationale des Constructeurs d'Automobiles): International trade organization representing the global automotive industry.

Producer Responsibility Organization (PRO): An entity that is either set up directly by a government or by producers in the context of EPR, to organize ELT management and associated requirements such as recovery targets.

Pyrolysis: Decomposition of ELT material into oil, gas, steel and char in different proportions depending on conditions under pressure and high temperatures and usually the absence of oxygen. Carbonisation, gasification and thermolysis are related recovery methods.

Reclamation/reclaim rubber process: Conversion of vulcanized rubber waste into a state in which it can be mixed, processed, and vulcanized again. Reclamation usually involves a chemical process. It is a recovery method. This does not refer to authorized landfill or backfilling in this case.

Reclaimed rubber: Rubber produced from the reclamation process, which can be vulcanized again.

Recovery application: The use of a recovery product (see below) e.g. tire granulate in rubber-modified asphalt.

Recovery method: The process used to treat an ELT e.g. granulation.

Recovery product: The output following processing through a recovery method e.g. tire granulate.

Recovery route (RR): The value chain from the point of collection, through processing and treatment methods to products and applications reaching end markets. For the purpose of this study, retreaded, reused, landfilled or stock-piled tires are not considered as ELT recovered.

Recycling: This involves reprocessing of articles such as ELT to produce products, materials or substances. This excludes the production of tire-derived fuel (see below).

Regrooving: Consists of cutting a pattern into the tire's base rubber.

Retreading: Also known as recapping or remoulding. Process of renewal of tires for reuse by replacing the worn-out rubber belts/treads with new ones.

State of knowledge (SOK): A review and analysis of the current information available on a topic. In this context the aim is to provide an overview of the ELT management systems in place including the ELT collection rates, recovery routes, and management methods.

Steel production: Use of ELT in the form of extracted tire-derived steel for the production of new iron, or steel in electric arc furnaces, steel mills and foundries for the manufacturing of secondary steel. Use of ELT in steel production is a recovery method.

Tire-derived material (TDM): Recovery sub-category. TDM is a product made from the recycled material of ELT.

Tire-derived fuel (TDF): Recovery sub-category. TDF is ELT used as an alternative fuel to produce energy through combustion (energy recovery). TDF also refers to the fuels produced by a specific treatment of ELT (such as pyrolysis, which can produce oil and gas output products along with a TDM portion). Although the use of ELT in cement production is considered both energy and material recovery, it is included in TDF for the purpose of the report.

Tire Industry Project (TIP) members: Bridgestone Corporation, **Continental** AG, **Cooper Tire & Rubber** Company, The **Goodyear** Tire & Rubber Company, **Hankook** Tire Co., Ltd., **Kumho Tire** Company Inc., Compagnie Générale des Établissements **Michelin**, **Pirelli** & C.S.p.A., **Sumitomo Rubber** Industries, Ltd., **Toyo Tire Corporation**., and The **Yokohama** Rubber Co., Ltd.

Total ELT generated (from available sources): Amount of ELT generated (in metric tons) according to the most reliable and comprehensive source available.

Total ELT recovered (excluding civil engineering and backfilling): Amount of ELT recovered (in metric tons), through material and energy recovery. This does not include any tires that are recovered for civil engineering and backfilling, abandoned, landfilled or stockpiled.

Total ELT recovered (including civil engineering and backfilling): Amount of ELT recovered (in metric tons), through material, energy recovery and civil engineering & backfilling. This does not include any tires that are abandoned, landfilled or stockpiled.

Types of vehicles:

- Passenger cars: road vehicles excluding motorcycles with a capacity of below nine people in total (i.e. nine seats or less - inspired by the OICA definition).
- Commercial vehicles: light duty commercial vehicles, coaches, buses, heavy duty vehicles such as trucks (inspired by the OICA definition). These will also include the OTR vehicles.
- Motorcycles: Two and three-wheeled motorized vehicles including mopeds, scooters and motorcycles.

Vehicles in use: All registered vehicles on the road during a given period-specific date (inspired by the OICA - definition).

Introduction

Formed in 2005, the Tire Industry Project (TIP) serves as a global, voluntary, CEO-led initiative, undertaken by 11 leading tire companies with an aim to anticipate, identify, analyze and address the potential human health and environmental impacts associated with tire development, use and management through end of life. TIP is a proactive organization that operates under the umbrella of the World Business Council for Sustainable Development (WBCSD) and is designed to advance sustainability throughout the industry. Together, TIP member companies work to collaborate on sustainability challenges facing the industry, improve understanding of and educate about these challenges, and develop potential solutions for a more sustainable future.

Context and objectives of the ELT project

The tire industry recognizes that there are both opportunities and challenges associated with tire manufacturing and sustainable development. By taking an early look at industry issues, TIP works to more fully understand environmental and health challenges pertinent to the tire industry and formulate an approach for making the industry more sustainable.

TIP has an objective to advance ELT management globally by engaging stakeholders in a process of identifying and sharing best practices.

Objectives of this study

This study has been conducted with the support of Deloitte to collect and summarize current information on ELT management practices and data for a selection of 45 countries.

The report’s analysis of the current ELT management in the countries within this scope includes:

- An overview of current and prospective regulations, ELT management systems (collection, transport & intermediate treatment stages);
- The distribution of ELT across recovery methods, products and applications;
- A better understanding of the feasibility of different recovery route categories and associated methods, products and applications.
- An overview of studies conducted on the risk of impacts on health and the environment and
- A panorama of advanced technology and innovations in ELT recovery to overcome risks and improve viability.

There is fairly good knowledge of ELT management and practices in Europe and countries such as the USA, Japan, South Korea and Brazil where the existence of regulatory authorities, trade associations or ELT management organizations allow the collection and consolidation of rather comprehensive data that can be easily accessed. However, there is still a diversity of methods used to obtain the data, with different vocabularies and different scopes covered (in terms of types of tires). Those countries and regions are also the ones with relatively mature ELT management systems and best practices to share.

On the other hand, limited information is publicly available in other key countries such as China, India, Argentina, Thailand and Nigeria for parts or all of the ELT market in certain cases. The lack of data availability can be explained by the coverage level of existing formal ELT management systems and reporting capacity for consolidating the data notably on specific distribution. The opportunities for the future of ELT management at the global level are tremendous in these countries. Limited knowledge of statistics and ELT practices can be an impediment to improving the local and global ELT management.

In addition, very heterogeneous practices can be observed in terms of ELT management from one country to another in terms of legislative framework, network organization and present and future markets for

Recovery Routes. A better knowledge of these practices will allow for the identification of good practices and opportunities for future collaboration with local stakeholders.

Therefore, the purpose of the state of knowledge (SOK) is to provide an overview of the current ELT management systems for a selection of 45 countries:

Argentina, Brazil, China, Europe (Throughout the report the scope for the region includes countries covered by the European Tyre & Rubber Manufacturers' Association scope [ETRMA]), India, Indonesia, Japan, Mexico, Nigeria, Russia, South Africa, South Korea, Thailand, and USA; which covers 83.5% of vehicles in use in the world (Source: OICA, 2015 data. Including the countries from the 2016-17 WBCSD TIP ELT study as shown in Figure 3, the coverage rate reaches 89%).

The main criterion used for the selection is the number of vehicles in use. We ensured that the selection includes the countries with the most important car markets, representative of different geographical zones. In relation to the last study conducted between 2016 and 2017[1], the scope of this present report focuses on countries identified as having well-established ELT management systems (including data availability), countries with particularly interesting dynamics regarding growth in recovery methods, products and applications markets, and countries that have significant potential for development in this domain. Nigeria was added to the scope due to its significant contribution to the number of vehicles in use and for the potential for development of a formal ELT management system and ELT markets in the country.

Methodological approach

The results of the study presented in this report are based on information collected via literature review and interviews with stakeholders.

A stakeholder mapping has been performed in order to include key stakeholders in the data collection and consultation process.

The findings presented in this report are solely based on the data sources presented above. The purpose of the study is to capture the best knowledge possible with the means and timeline defined for the project. Efforts have been made in order to avoid introducing biased opinions in the data collected through the interviewees, by presenting the most factual information possible and being transparent about the sources of information. It is important to note that the intention of the study is not to audit nor validate the data collected from different sources.

The quality of quantitative data collected on ELT management varies from one country to another:

- Countries where there is no formal organization in charge of the ELT management at the national level generally suffer from a lack of reliable consolidated data. Inconsistent data from different sources can be observed in these cases.
- Even in countries where official data is published by a formal, well-recognized organization, it still needs to be interpreted with caution. For instance, ELT generated by ELV are not always included in the consolidated data.

Another limitation is related to the share of ELT from illegal import, treated by illegal operators or never declared by legal operators, which can constitute quite a significant volume, even in countries with a mature ELT system. The share is not included in the official consolidated data where the volume of total ELT generated is underestimated and the recovery rate can be overestimated.

Retreading and reusing tires that can still meet safety standards can reduce ELT generation by prolonging the lifespan of the product. However, these practices are generally limited, due to technical and safety reasons, to specific tyre categories, such as truck and bus, OTR, agricultural, and airplane tyres. In some countries, retreaded and reused tires are included in the official recovery rates. However, quantifying the amount of these tires reinjected in the market is not always possible and the reliability of the data can be questionable because assumptions are often used regarding the number of times a tire can be retreaded/reused. For this reason, the data presented in this study focuses only on ELT.

Therefore, the data presented in this study needs to be interpreted carefully. For more information regarding the limitations, assumptions and scopes of the data collected and consolidated in the study and the assessment of the data reliability, please refer to the chapter “Part I: State of Knowledge on Targeted Regions/Countries”.

We would like to thank all of those who kindly participated in the study, through interviews or by other means, supporting the completion of this project.

[1] Other countries studied in 2016-17 included: Australia, Canada, Malaysia, Morocco, New Zealand, Saudi Arabia, and Ukraine.

Part I: State of Knowledge on Targeted Regions/Countries

The purpose of this SOK is to get an overview of the current ELT management systems for a selection of countries: Argentina, Brazil, China, Europe, India, Indonesia, Japan, Mexico, Nigeria, Russia, South Africa, South Korea, Thailand, and USA. This chapter will summarize this SOK based on individual reports.

Methodology on data collection, consolidation and limitations

As stated in the Introduction, the information presented in this chapter has been collected through two main approaches:

1. Literature review such as public studies, public databases and statistics, academic studies, existing and emerging regulations, etc.
2. Stakeholder consultation process based on interviews. In some cases, mainly for language barriers, the information was collected via written feedback after an interview guide was sent to the interviewee.

For the purpose of comparing the different countries' performances in terms of ELT management, a set of definitions and scopes have been used. For this reason, the data available in the different sources has been adjusted when necessary in order to align the definitions and scopes with those used in this study. The definitions (such as what is excluded/included in ELT) is explained in the chapter "Glossary of terms used" of this document. Nevertheless, the following elements must be taken into account when analyzing the data included in this study:

- The following is NOT considered as ELT and will therefore be excluded from data: retread tires, second-hand tires and tires exported with used cars. This change in scope is the main reason why some of the Recovery Routes communicated in the study may vary from the source data.

- When possible, the most recent source of data (mostly 2017) has been used. However, it's important to note that not all of the countries have data corresponding to the same year. No extrapolations have been made for alignment to a given base year.

- When available, the unit used to measure ELT management indicators is metric tons. Conversions between short tons (USA) to metric tons or from number of units to tons have been made where necessary. Data regarding ELT generation in Mexico and India are available in number of tires and not in tons. An estimation of 10kg/tire has been used for Mexico and an average of 8kg/tire in the case of India.

- The ideal target scope for this study includes all types of tires: passenger car, truck, and airplane, agricultural, two and three-wheel as well as OTR tires. Nevertheless, the data presented hereafter is limited to the scope of each source of data found. Passenger cars, bus tires and truck tires are included in all of the country/region data (these are the most significant quantities in terms of units of ELT generated). OTR tires (an important category because of the significant weight per tire) and the other categories are not always included in the source data. The completeness of data with regards to our target scope is evaluated in each country/region report. Where possible, the missing ELT categories are specified.

A cross analysis of data consistency between different sources has been performed to conclude the data reliability. Regarding the quantity of ELT generated, the data collected at the local level has been compared with the data estimated based on the number of vehicles in use published by OICA (2015 data). In case of significant inconsistency and where the level of credibility is deemed equal, the data which gives the lower recovery rate is used as a precaution to avoid overestimation.

- In order to further analyze the consolidated data, the different recovery routes have been grouped within the following three categories: material recovery (excluding civil engineering & backfilling), energy recovery and civil engineering & backfilling. Although for some recovery routes, the split between material and energy recovery is debatable, we have calculated the tons of ELT recovered based on the following assumptions:

- Tons of ELT used in cement kilns: 75% energy recovery and 25% material recovery[2];
- Steel production (except when ELT is burnt as a TDF): 100% material recovery;
- Pyrolysis: 100% material recovery;
- When recovered through an unknown means of recovery, or when data available regarding exportation of shredded tires: 50% energy recovery and 50% material recovery.

Data collection on ELT management across the countries studied generally includes a combination of real data and estimations. A number of best practices have been identified to ensure data is the most reliable. For the USA, the data published by the U.S. Tire Manufacturers Association (USTMA) is drawn from multiple sources including surveys of state regulators and scrap tire processors, interviews with experts and end users, as well as trade association and other industry data. Similarly, ETRMA gets data for its Europe scope from collection and processing organizations including ELT management companies, ETRMA member companies, EU (including Eurostat) and national waste statistics, and annual reports from Producer Responsibility Organizations (PROs), or national EPR reports for example. The consolidation of these different sources of data and consistency checks on overlapping or duplicate figures enhances the reliability of data collection.

Trade associations have a key role to play as an intermediary and point of consolidation of information in both system management but also data collection. When these actors or an equivalent are responsible for ensuring correct collection and distribution data this facilitates and further reinforces the reliability of data collection.

Overall, the ELT generation statistics are based on tire sales with some adjustments. Estimations are usually made on this basis (e.g. Nigeria). This information can be collected through declarations on production and imports (e.g. the information requested by the Brazilian Institute of the Environment and Renewable Resources [IBAMA] for Brazil). For South Korea for example, the Korea Tire Manufacturers Association (KOTMA) calculates ELT generation based on a wear rate applied to sales in a given year.

It is important to note that for European countries, for example, as in other countries, the quantity sold onto the market equates to the quantity dismounted. Therefore, both end-of-life vehicles and historical stockpiles are excluded. In addition, illegal activity and non-declaration that will not be accounted for in generation statistics but could be included in treatment.

Where possible, statistics on recovery methods, products, and applications, can be drawn from tracking data related to validated treatment (e.g. as understood to be used in Japan and South Korea).

The following table could serve as a template for the general statistics on ELT management in a country.

ELT data scope/ category (Units: mass or number of tires by type e.g. truck or car)

Total ELT Generated (from available sources based on replacement tire sales)
Total ELT Recovered
Sub-total Material Recovery
Sub-totals recovery methods, products and applications
Sub-total Energy Recovery
Sub-totals recovery methods, products and applications
Sub-total Civil engineering and backfilling
Sub-totals recovery methods, products and applications
Total ELT non-recovered/ unknown

Table 1 General categories of ELT Management

[2] Based on ETRMA, End-of-life Tire Report 2015.

Summary and cross-analysis of the ELT markets

There are many different ways to recover ELT that can be grouped into the following three categories:

- Material recovery
- Energy recovery
- Civil engineering and backfilling: tires can also be used in 1) civil engineering as water retention basins, tire-derived aggregates for road construction, etc., and 2) as backfilling (land rehabilitation or backfilling in mining sites).

According to the data collected during this study, the total amount of ELT recovered in the 13 countries and the European region amounts to approximately 25.7 million metric tons per year and 26.1 million tons per year if we consider civil engineering and backfilling as a recovery route. The overall amount of ELT generated in these countries is estimated to be 29.1 million tons.

The countries that recover the most ELT in volumes are China, India, United States (USA) and Europe as illustrated in Figure 1.

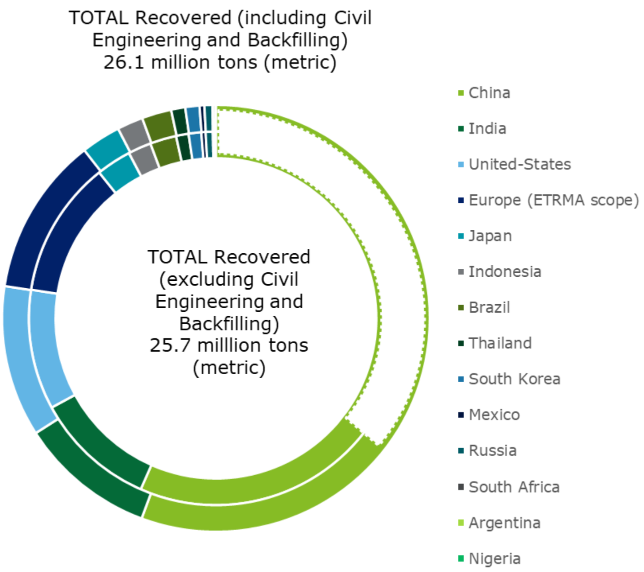


Figure 1. Total ELT recovered in the scope and contribution by country/region. Note that for China, the highlighted blank portion within the dotted line is unconfirmed/ not formally registered, which is therefore ELT collected with undetermined end use.

However, the number of ELT recovered per year in a given country needs to be put into perspective with the amount of ELT generated. The recovery rate (total tons of ELT recovered / total tons of ELT generated) seems to be the best indicator to analyze the performance of the ELT market in a given region.

For this study, two different recovery rates are calculated depending on whether "civil engineering and backfilling" is considered as a recovery route. In the recovery rate where it is not considered as such, the amount would be considered as non-recovered or equivalent to landfill disposal. The distinction is made since considering these two ELT end-markets as a means of material recovery is debatable (especially when referring to backfilling in mining sites).

China, Brazil and India are identified as having the highest recovery rates within the selected countries (Figure 3 below). Brazil, which has an EPR system, has been increasing its recovery rate approaching targets through delivery to cement kilns and granulators. For both China and India, around two thirds of recovery is understood to occur in informal markets. The volumes of ELT generated in China far outweigh the quantities in other countries, the most significant recovery route being reclaim rubber technologies. In India, besides energy recovery and reclaim rubber, applications include artisanal products, use on fishing boats, roofs-tops or swings. ELT are therefore seen as a valuable material in India for various applications. In the future, in the context of a growing middle class, this recovery rate might decline.

Europe's recovery rate was 92% in 2017[3] with 1.9 million tons in material recovery, 1.2 million tons in energy recovery and 0.1 million tons in civil engineering, public works and backfilling.

ELT recycling markets worldwide are mainly driven by the regulatory context in each country. Government regulations are enacted to address environmental issues related to illegal dumping or importation of ELT as well as historical stock piles leading to public health and sanitary issues (e.g. fire hazards, breeding ground for mosquitoes and vermin, and the current issue of the Zika virus etc.) that can be the result of ELT collection and processing systems not functioning.

Overview of recovery methods, products and applications

The rate of growth and viability of different recovery markets at a given time are directly linked to the demand for the recovery products.

In the case of TDF, this may be the most volatile. When traditional fuels are relatively cheap (recently natural gas

[3] Unlike ETRMA statistics for overall recovery rates, this study focuses on End of Life Tires only, and consequently excludes quantities processed through retread, reuse, and export from its scope, effectively reducing the recovery rate.

in the USA for example), demand for TDF as an alternative may be weaker.

Generally, energy recovery is a straight-forward means of recovery requiring limited processing and treatment. This explains why it makes up half of the ELT market in the USA (mainly use in cement kilns but also the pulp and paper industry and utilities) and South Korea (where there is a limit of the portion of ELT being sent for energy recovery, set at 70%) and even up to 40% in Europe, where material recovery is prioritized over energy recovery. In Japan, unlike other governments' policies, there is active promotion of the use of TDF through the country's energy policy (exemptions from reduction objectives) and ELT mainly becomes TDF for paper manufacturing boilers. Brazil also has a high rate and depends in particular on consumption by the cement industry (energy and material recovery).

For material recovery including the production of rubber granulate, facilities often have relatively high costs such as initial capital expenditure. Another key element is the need to develop secondary and end use industries to absorb the ELT product. As aforementioned, in Europe, material recovery is generally prioritized over energy recovery and makes up approximately half of ELT recovered. In Russia, policy directs ELT to material recovery, as energy recovery is not eligible to meet ELT management targets. A quarter of ELT generated in the USA becomes rubber granulate with applications including molded rubber products, playgrounds, sports facilities and asphalt. In California, material recovery is prioritized in particular. Material recovery makes up less than a quarter of ELT recovered in South Korea. It is important to note that the production of reclaim rubber is particularly predominant in Asia.

The recovery methods of pyrolysis and gasification are also significant in Asia for example in Indonesia, Thailand and Japan, which may have different levels of quality of end products. Pyrolysis is only slowly developing in the USA with some pilot plants. Overall, this recovery method has had some difficulty commercializing products and has been facing operational risk including safety hazards and air polluting emissions.

For the application of ELT in civil engineering and backfilling, there has been significant growth in the USA over the past decade to reach 10% of the ELT market.

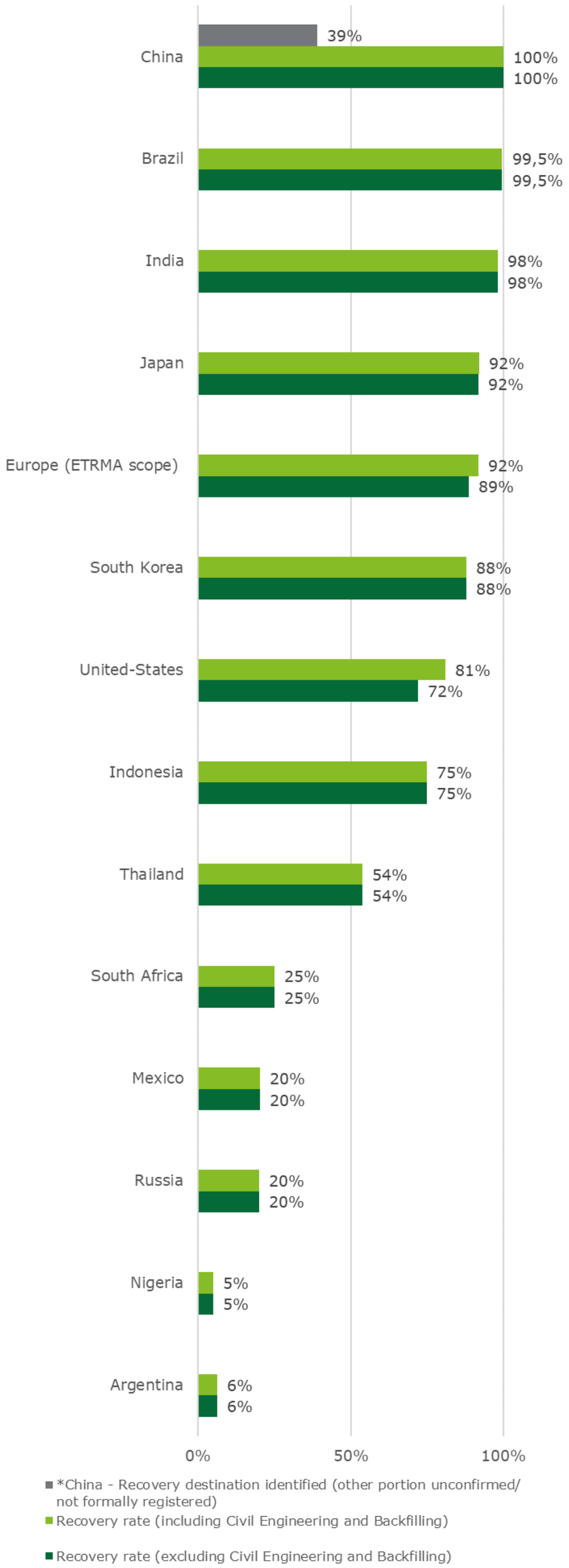


Figure 2. Recovery rates by country/region

Regulation or intervention of public authorities

A minimum level of some form of intervention from the government is very often necessary in order to properly develop the ELT recycling industry.

In some countries, the role of the government is limited to the organization of the ELT stakeholders, or can be more interventionist regarding financial and technological development of the sector. Globally speaking, the development of ELT recycling markets is still quite recent. Although some recovery methods, products and applications are more profitable than others and examples of success stories exist in some regions, taken as a whole, the ELT market has been struggling to be profitable and self-sufficient. Financial support with a formalized ELT management system is very often an important factor to increase the competitiveness of the industry and achieve high recovery rates.

Different ELT management systems exist at the national level. Within the scope of our study, three main systems have been identified:

EPR system or take-back obligation system: In this system the responsibility for collecting and ensuring treatment of ELT is imposed on the actors that put new tires onto the market (tire manufacturers and importers) through an eco-fee. This is a very common configuration in European countries including Hungary, Italy, France, Spain, Netherlands, Sweden, Turkey, Belgium, Portugal, Finland, Estonia, Latvia, Lithuania, Greece, Slovenia, Czech Republic, Slovakia, and Ireland and is also used by Brazil, South Korea and Russia.

The system usually involves these actors setting up a non-profit organization (or PRO) that manages the collection and recovery of the end of life product. The extra cost is generally passed onto the consumers, with an environmental fee (eco-fee) added to the product price.

Government responsibility financed through a tax: In this system, the responsibility lies with the state and collection and recovery are financed by a tax on production which is passed on to the consumer. The few countries that run such a system include Denmark, Slovakia and Croatia.

Free market system: In this system, the state or federal legislation may set action plans (qualitative objectives) or obligations to have an ELT management plan (e.g. Mexico), however responsibility (eco-tax or eco-fee) is not imposed upon particular actors. The countries with this system are Argentina, China, India, Indonesia, Japan, Mexico, Nigeria, Thailand, UK, Germany, Switzerland, Austria, Serbia and the USA.

A comparison of the different ELT management systems/schemes is shown in Table 2.

Table 2. Comparative table of ELT management systems/schemes

	Responsible actor(s)	Governance	Funding	Key features
01 **Free market system**	Under a free market system, the legislator enacts objectives to be met, however there are **no responsible parties directly designed**.	Usually no dedicated organization, ELT issues are covered by more general waste-related regulation and governance system. However, the existence of an **industry association** in charge of promoting responsible ELT management is common practice.	**No regulated eco-fee** collected for ELT management; free market.	- **Minimum state intervention.** **- Less producer involvement.** - **Market forces** being the main driver for ELT management, i.e. the most mature and cost-effective recovery routes representing the biggest share of the market. - Cooperation of companies on a **voluntary basis** to promote best practices. - More **difficult** for **more environmentally-friendly** Recovery Routes to develop, if not economically interesting at the beginning.
02 **Tax system**	Under a tax system, the **State** is responsible for ELT recovery.	The **State** is responsible overall for the organization of ELT management and remunerates the operators in the recovery chain.	ELT management financed through a **tax levied on tire manufacturers and importers** and paid to the State, and subsequently **passed on to consumers**.	- The State guarantees a **level playing field** by enforcing the same product standards on all tire producers. - Taxes may have the effect of **favoring more environmentally-friendly** recovery routes (e.g. material recovery over energy recovery) and prohibiting landfill.

03 **Extended producer responsibility (EPR) system**	The **producer of tires (manufacturer or importer)** is held responsible by law to organize the ELT management, with **targeted volumes** defined based on the quantities of tires put onto market.	Producers can either set up their **individual management system** or gather to set up a **producer responsibility organization (PRO)** (the latter representing the majority of cases). The organization is in charge of managing the collection and recovery of a volume of ELT defined by regulation.	ELT management financed through an **eco-fee** on manufactured and imported tires, **paid by producers,** usually **passed on to consumers.** The amount of the eco-fee depends on the cost related to ELT management and the secondary markets. It usually decreases over time, as the ELT management gets more and more mature and economically efficient.	**- Cost optimization** enabled by the creation of a **PRO.** - Better **data traceability** through **reporting obligations**. - Better transparency on how the eco-fee is used. - **PRO** having the flexibility to determine **the most cost-effective solutions** to recover ELT or to favor the **most sustainable** options. - **Lack of competition in some countries** for the ELT market with the creation of Producer Responsibility Organizations.

In practice, hybrid systems can be implemented. For instance, the USA operates generally under a free market system, however some states can spontaneously influence markets with grants, taxes and subsidies.

The free market system presented above refers to countries where a legal structure has been defined for ELT management. In countries with weak regulation or non-existing regulation related to ELT management, the recycling market may still be freely developed with an important proportion of informal sectors on a small scale when ELT represents a source of value, leading to illegal operations with sanitation, environment, fire and safety risks.

Whenever an EPR system exists, there is usually an organization at national/state/province level in charge of the ELT coordination. Similar organizations exist in a free market system when legal regulation requires coordination between actors (such as the Mexican Management Plans for example). Usually, these organizations are created by the tire manufacturers.

The eco-fees or taxes, paid by manufacturers or consumers, are therefore used by the dedicated organization to finance the following activities:

- Collection, transportation; shredding/granulation, gate fee for granulators;
- Development grants and loans, R&D and partnerships to develop new markets for recycling;
- Subventions to encourage certain recovery routes that would not be profitable otherwise;
- The construction of treatment plants that in turn are sold on at a low price in order to increase recycling capacity and decrease the initial investment costs for recyclers (e.g. South Africa);
- Public awareness raising;
- Stockpile abatement (e.g. New Jersey, New York, USA) and illegal dump site cleanup (e.g. in the USA);
- ELT program management (licensing, enforcement, inspections), administration of ELT collection (e.g. in the USA);
- Tire fire cleanup (e.g. in Arizona, USA);
- Mosquito control (e.g. in Florida, USA); and
- Air pollution control (e.g. in California, USA).

Of course, how the fees are used can vary from one system to another. In free markets, there is a greater focus on raising public awareness in order to respect the competitiveness of the market. In more interventionist systems, regulations will favor some recovery routes over others (for example, material recovery over energy recovery for Russia, the EU, South Korea, and California in the USA).

There can be issues related to competitiveness when different systems are set up in broader regions. For instance, French granulators benefit from the financial support with the eco-fee paid by tire manufacturers (collection fee, gate fee), while the ELT are managed under a free market principle in Germany.

In case of a free market, energy recovery can be a very efficient way to deal with high volumes of ELT since it helps to get rid of long-standing stockpiles easily and requires relatively low investment. This is because whole, cut or shredded tires can be directly used as an alternative fuel. Nevertheless, as a general trend, once a country has established a more mature approach to ELT management, material recovery is often supported through policy-making. This evolution is in line with the waste hierarchy ladder and circular economy principles. This option is considered preferable in terms of environmental impact assessment and resource efficiency.

Although material recovery might require more initial investments, R&D efforts or partnerships with actors from new industries, it also generates products with higher added-values.

The ideal long-term vision for the ELT industry would be to find new or existing markets for ELT recycling that could help prioritize high-value products in order to generate enough revenue for the industry to be self-sufficient.

Some countries have very low awareness of the environmental and public health risks related to ELT, including the public authorities themselves. An important volume of tires is therefore simply dumped on the side of the road or abandoned in fields. This is a particularly significant problem when the ELT management system does not function, leading to stockpiles.

There is also a considerable but unquantifiable amount of ELT burnt or commercialized in black markets. This results in squandering of resources and a significant impact on environment and public health through mosquito transmitted-diseases, fire hazards, or lack of pollution abatement system, etc. In these countries, the government has a crucial role to play. A push from public policy makers is needed in order to raise awareness among the general public and public sector actors to set up a system to deal with ELT properly. Likewise, it is key to enforce sanctions of illegal activities and provide adequate investment for the resources needed to carry out inspections and enforce regulations.

Developing countries often lack high technology recycling factories, expertise, technical know-how and facilities to handle ELT. These countries could use the support from more experienced actors in developed countries in order to leapfrog to a successful ELT market.

Approaches to establishing a successful ELT management system including supporting factors (best practices) and challenges faced

There is no one size fits all approach to establishing a well-functioning ELT management system. In Europe for example, there is a broad mix of different management systems including EPR, free market and tax based systems and overall the recovery rate is high.

Out of the three main systems outlined above, there are advantages and potential disadvantages to each. One of the indicators of success of a system is the recovery rate in relation to the total ELT generated. Best practices can usually be identified in countries with high recovery rates as contributing elements to achieving these rates as identified below.

Trade associations have a key role to play in the success of ELT management through coordination at industry level. These associations can be pre-existing groups of companies in the same industry or specifically set up as an intermediary coordinator in the domain of ELT management. ELT management is usually successful when large associations are mandated to manage ELT as a cooperative organization (e.g. Reciclanip and EcoTyresUnion covering the majority of ELT generated in Brazil and Russia respectively) providing a form of critical mass to drive system and the processes of collection, treatment and application practices.

The designation of government agencies (e.g. CalRecycle in California) or non-government agencies to manage solid waste or if possible ELT in particular is another best practice.

In Brazil, an EPR system is in place, which involves regular weekly calculations by the government agency IBAMA based on declarations regarding production, imports and sales. The EPR system in South Korea also involves monitoring and control from the Ministry of Environment. For control in particular, a degree of resources and capacity is required that may not be possible in all countries. Monitoring through reports submitted by manufacturers and importers. Smaller actors may not always comply with reporting requirements (e.g. in Brazil).

The EPR system in South Korea includes a framework for recovery plans established every five years setting out roles and responsibilities for different actors. In Mexico, where the recovery rate is relatively low, a management plan required but it is deemed flexible in terms of content (i.e. no fees and no rate of ELT collection).

Where fees are charged, (e.g. through the EPR system in South Korea to manufacturers and importers or in the free market on new tires in the US, in New York and California) as well as tax-based systems, the financing can go towards research and development, start up funding and promotion of recovery. A best practice is when the funding is earmarked for ELT management. In Brazil the costs will now be shared by municipalities and car dealers to spread costs. Governments can also issue punitive fines, which is a measure of enforcement where necessary and can also contribute to these funds. In South Africa, where there has been a recent change in management, funding had also been directed towards the development of secondary industries, which is very important for the development of capacity of absorption and long-term demand. It is worth noting that demand is currently low for rubber granulate in Russia for example, where material recovery has specific targets.

In EPR systems, there are different ways in which mandatory recovery quantities are set around the world. In South Korea this takes into account past ELT recovery and business forecasts. In Russia, which recently implemented EPR, an annual incremental rise in the recovery rate is being used to develop the system.

In free markets on the other hand, such as the USA or in the UK (where there are also reporting obligations, which support the ELT management system), ELT is directed towards the lowest gate fee, which as the charge to waste reception determines the most efficient use of ELT. The free market in Japan is also supported by waste regulation providing some framework favorable to a higher recovery rate.

Other measures of a degree of government intervention can occur in free market systems to support ELT management and recovery industries. For example, states in the USA are providing grants and funding for stockpile clean up and subsidies to recovery facilities. EPR systems also have funding schemes. For example, the Brazilian development bank provides funding for shredding companies in particular. In Argentina, where the recovery rate is particularly low there is currently a lack of investment and funding in recovery facilities.

In India and Indonesia informal markets allow for particularly high collection and recovery rates, which are supported by a significant number of independent collectors and treatment facilities.

Many countries have indicated a potential shift towards EPR notably from free market systems, for example in Mexico, Thailand, Argentina and Nigeria, where recovery rates are low and the free market may not be functioning but also in India where the recovery rate is very high but the system is largely informal. This shift to EPR from free market was made most recently by Ireland in 2017. On the other hand, it has been foreseen, once markets are established, that the EPR system in place in South Korea could become a free market.

As a major challenge in some countries such as Mexico, South Africa, Indonesia, Argentina and Nigeria, supporting logistics and transportation can lead to a successful ELT management system. For example, establishing hubs between collection and processing or organizing delivery direct to processing if in close proximity. For example in Brazil, there is a requirement for reception points for tires in every city with a population of over 100,000. Funding for collection and transportation through eco-fees has also been a measure implemented.

Potential impacts on the environment and health of recovery methods, products and applications

With regards to ELT granulate, studies have focused predominantly on the risk to human health from exposure on artificial sports fields in particular the USA and in Europe. However, some individual studies have looked at different recovery methods elsewhere in the world.

Numerous studies have been conducted related to the use of granulate in turf fields. Overall, the conclusiveness has not found consensus due to the narrow scope and multiple variables leading to overall uncertainty regarding the potential impacts.

In February 2017, the European Chemicals Agency (ECHA) published the report "An evaluation of the possible health risks of recycled rubber granules used as infill in synthetic turf sports fields", which concluded that there was a very low level of concern regarding exposure to granules (ECHA, 2017b).

In September 2018, the French research institution ANSES (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail) found that the risk of exposure to granulate in synthetic turf rubber infill was negligible to human health but there was a risk to the environment through transfer of zinc and phenols and that additional measures should be taken in terms of risk assessments and the methodologies of evaluations (ANSES, 2018).

Studies on the impact of health and the environment continue to focus on the use of granulate on artificial turf and are ongoing. Most recently, the committees for risk assessment and socio-economic analysis of the ECHA adopted and drafted opinions respectively supporting a restriction proposal of the Netherlands to not place granules and mulches on the market if the sum of identified polycyclic aromatic hydrocarbons is greater than 20 mg/kg to further reduce risk of an impact on human health (ECHA, 2019).

ETRMA published a statement on the safety of recycled rubber infill material in 2016. Rubber components which can come into direct contact with the general public must comply with EU REACH restrictions. Out of the 70 scientific reports and articles published worldwide by the time of writing of the ETRMA statement in 2016, many conclude that "there is no significant or scientifically justified risk associated to the use of rubber granules made from end of life tires" (ETRMA, 2016).

The study conducted by Institute Mario Negri IRCC found that the eight PAH covered by REACH Regulation restrictions were at levels lower than limits for public sale (TRR, 2017).

In the context of REACH, the European industry aims to clarify possible health concerns about the use of ELT derived materials on certain applications. For this purpose ETRMA, with the involvement of different actors from the value chain, has promoted the development of the European Risk Assessment Study on Synthetic Turf Rubber Infill named ERASSTRI involving 28 partners from 14 European countries (ETRMA, 2019).

The results of the study are expected to be published in the first half of 2020 (ETRMA, 2019)

Advanced technologies and innovations in ELT recovery

During the study, it was identified that research institutions in most countries have initiated some form of research on the use of ELT. A variety of different trends have been observed regarding research in particular, some being specific to different countries on advanced ELT technologies and innovations.

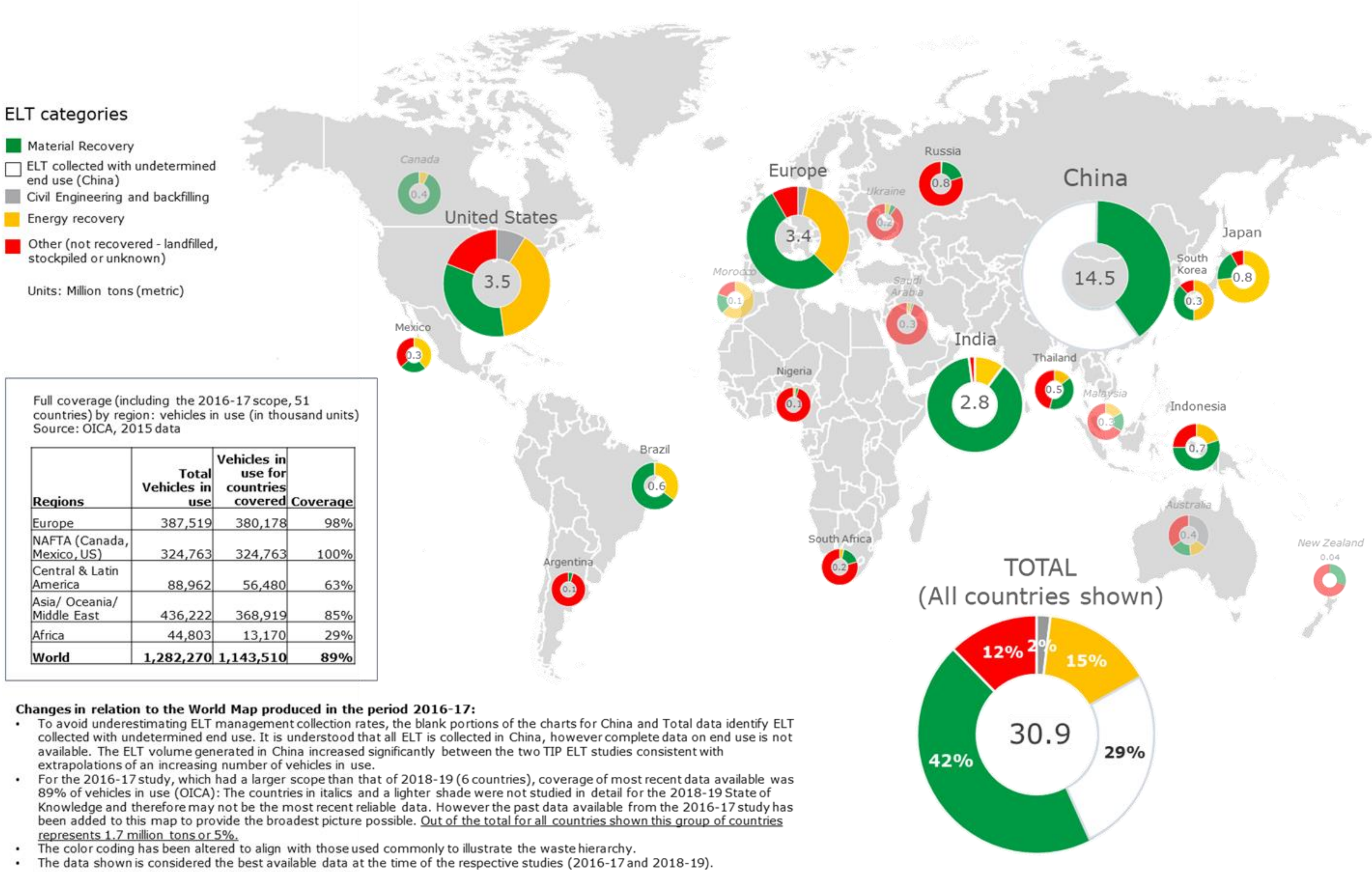
The majority identified were material recovery based research projects in line with the waste hierarchy promoting material recovery. For example, in South Korea, research has given particular attention to the use of ELT to form composites from polypropylene and TDM. Incorporation into plastics has been studied in Europe.

A number of research institutions and projects have focused on the development of pyrolysis as a recovery method and the products of the process. In Europe, research has given attention to high quality oil and carbon black and in South Africa, char as products of pyrolysis. In Russia, a form of accelerated pyrolysis is being studied. Work in China is focusing on low emissions pyrolysis technology. In the USA, studies have recently been conducted on the potential use of carbon from ELT in the production of batteries.

Institutions in countries have adapted the use of ELT to specific contexts, such as research in Nigeria, in which researchers have given particular attention to the capacity of ELT granulate to absorb oil from spills and other substances in wastewater. This capacity has also been studied in Brazil and USA. In Japan, civil engineering projects have focused on the use of ELT in structures faced with risks of earthquakes or tsunamis. Research institutions in Mexico, Brazil, India, Thailand and the USA have also focused on the use of ELT to reinforce concrete.

Rubberised asphalt has had continued study to understand its potential in Europe, Indonesia, Mexico Nigeria, South Korea and USA.

Studies into devulcanization have been conducted in Brazil. Various other applications have been identified, including porous pipes in Brazil, roofing and tiles in Argentina, and panels and matting in USA, and soundproofing in Indonesia.



Full coverage (including the 2016-17 scope, 51 countries) by region: vehicles in use (in thousand units)
Source: OICA, 2015 data

Regions	Total Vehicles in use	Vehicles in use for countries covered	Coverage
Europe	387,519	380,178	98%
NAFTA (Canada, Mexico, US)	324,763	324,763	100%
Central & Latin America	88,962	56,480	63%
Asia/ Oceania/ Middle East	436,222	368,919	85%
Africa	44,803	13,170	29%
World	**1,282,270**	**1,143,510**	**89%**

Changes in relation to the World Map produced in the period 2016-17:

- To avoid underestimating ELT management collection rates, the blank portions of the charts for China and Total data identify ELT collected with undetermined end use. It is understood that all ELT is collected in China, however complete data on end use is not available. The ELT volume generated in China increased significantly between the two TIP ELT studies consistent with extrapolations of an increasing number of vehicles in use.
- For the 2016-17 study, which had a larger scope than that of 2018-19 (6 countries), coverage of most recent data available was 89% of vehicles in use (OICA): The countries in italics and a lighter shade were not studied in detail for the 2018-19 State of Knowledge and therefore may not be the most recent reliable data. However the past data available from the 2016-17 study has been added to this map to provide the broadest picture possible. Out of the total for all countries shown this group of countries represents 1.7 million tons or 5%.
- The color coding has been altered to align with those used commonly to illustrate the waste hierarchy.
- The data shown is considered the best available data at the time of the respective studies (2016-17 and 2018-19).

Figure 3 ELT Generation and recovery by country/region (map) - This information has been modified for some countries in order to align definitions and units. Please refer to the limitations of this chapter.

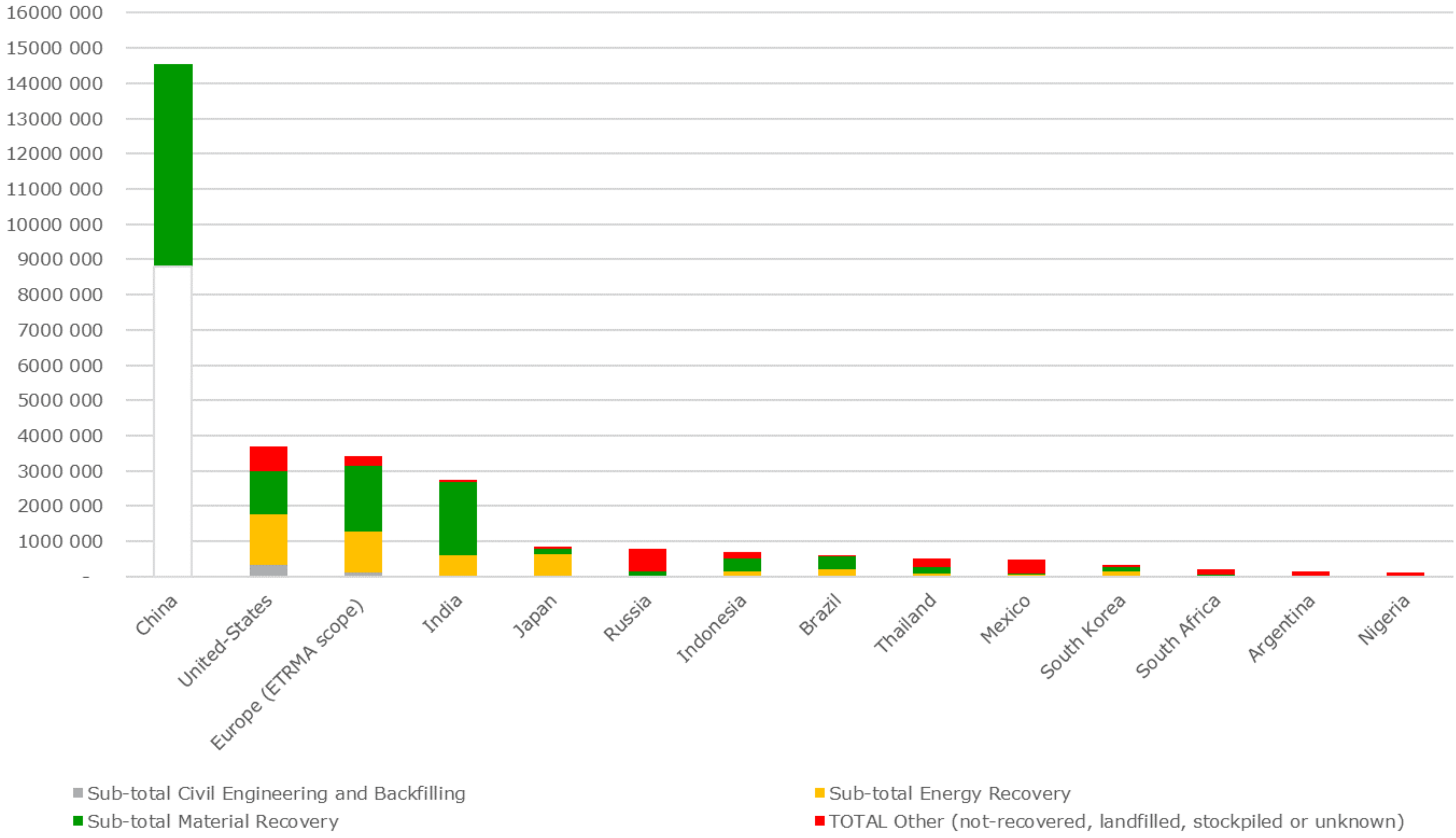


Figure 4 ELT Generation and recovery by country/region (graph). *Note for China: the blank portion highlighted shows ELT collected with undetermined end use.*

Summary for each region/country

A brief summary of the current state and local context surrounding ELT management in each country/region is given below. The countries are listed in alphabetical order.

Argentina

Argentina

Argentina

ELT data (Casa Rosada, BAE, 2019)	Kilotons (metric) (2018)	Percentage of total ELT generated (2018)
TOTAL ELT Generated (from available sources)	**150**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**9.6**	**6.4%**
TOTAL Recovered (including Civil Engineering and backfilling)	**9.6**	**6.4%**
Sub-total Material Recovery	9.6	6.4%
Sub-total Energy Recovery	0	-
Sub-total Civil Engineering and backfilling	0	-
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**140.4**	**93.6%**

Data availability and robustness: *The most recent data available was reported by Casa Rosada for generation and the publication BAE for recovery (extrapolated from monthly processing). The latter only includes the amount of ELT processed by the organization Regomax for the granulation of rubber.

Legal system: A free market system is in place. The development of ELT management in this country is mainly due to two factors: the existing frameworks regarding general waste and ELT treatment (which is primarily concentrated in the Buenos Aires region) and the business opportunity of sport infrastructures in the country.

Major changes in legislation/policy since 2016: An EPR system was under evaluation by the Ministry of Environment and Sustainable Development and being debated in congress. Since the beginning of 2019, a new provincial law (No. 9143) has been implemented in the Mendoza, making municipalities responsible for the collection and treatment of ELT.

Main ELT management organization: The Ecological Coordination Society of the State Metropolitan Area (CEASME) – an organization created by the Province of Buenos Aires and the city of Buenos Aires for the integrated management of municipal solid waste in the metropolitan area. INTI, an institute in charge of contributing to the development of the rubber industry through quality control, technical assistance, technological development and specific training of technicians and professionals, manufacturers or users of rubber products.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated): Based on collected data, the recovery rate is of approximately 6%. The main recovery route in the country is granulation of ELT for application on sports surfaces (material recovery).

Impacts on health and on the environment: In general, the municipalities evaluate the health risks posed by discarded ELT, especially diseases such as dengue and rodents, indicating insufficient collection processes and the limited functioning of an ELT management system.

Technological innovations:
- Material: Ecological Roofing Tiles made with recycled rubber from ELT (2014).

Opportunities and drivers:
- An EPR system has been under evaluation by the Ministry of Environment and Sustainable Development and a bill has been proposed.

Barriers and challenges:
- Lack of a legal framework concerning ELT management and the need for financial support in the treatment process.
- An awareness campaign could help reduce the informal market of ELT.

Brazil

Brazil

Brazil

ELT data (IBAMA 2017)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**587.9**	
TOTAL Recovered (excluding Civil Engineering and backfilling)	**585.2**	**99.5%**
TOTAL Recovered (including Civil Engineering and backfilling)	**585.2**	**99.5%**
Sub-total Material Recovery	379.1	64.5%
Sub-total Energy Recovery	206.1	35%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	2.7	**0.5%**

Data availability and robustness: Data provided for 2016 and 2017 from both IBAMA and Reciclanip.

Legal system: An EPR system with reverse logistics regulates ELT management in Brazil, in addition to laws regarding hazardous waste and disposal.

Major changes in legislation/policy since 2016: No changes to note.

Main ELT management organization: IBAMA, the Brazilian Institute of the Environment and Renewable Natural Resources, is the main organization which handles the EPR system, and determines ELT recovery targets. Reciclanip, a non-governmantal organisation, gathers 12 tire manufacturers, and handles all technical and operational aspects of tire recovery and monitoring for these manufacturers.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated): Material and energy recovery routes are widely used in Brazil. However, material recovery prevails over energy recovery in 2017.

Impacts on health and on the environment:
- No information available.

Technological innovations:
- Material: Devulcanization, Use of ELT in composites, concrete modified with crushed rubber.
- Civil engineering: Study on pipes made with recycled rubber.

Opportunities and drivers:
- Well-established ELT management system, and organization with significant national coverage (Reciclanip) handling waste tire recycling and recovery for over 80% of nationally generated ELT.
- Strong energy recovery sector (cement kilns).

Barriers and challenges:
- While being a very popular recovery route, the ELT management system relies significantly on cement kilns.

China

China

China

ELT data (CRIA, 2019 & CTRA, 2018)	Kilotons (metric) (2018)	Percentage of total ELT generated (2018)
TOTAL ELT Generated (from available sources)	**14545**	**100%**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**5650**	**39%**
TOTAL Recovered (including Civil Engineering and backfilling)	**5650**	**39%**
Sub-total Material Recovery	**5650**	**39%**
Sub-total Energy Recovery	**0**	**0%**
Sub-total Civil Engineering and backfilling	**0**	**0%**
TOTAL Other (ELT collected with undetermined end use)	**8895**	**61%**

Data availability and robustness: The figures for generation and recovery presented in this table are midway between consistent data provided by CTRA and CRIA. It is understood that all ELT is collected. There is uncertainty however regarding the end use for a large portion of ELT collected, which is therefore identified as ELT collected with undetermined end use.

Legal system: ELT are not currently managed within a structured management system, however there is indication of the possibility of policy development urged by growing environmental considerations.

Major changes in legislation/policy since 2016: There have been no major changes in legislation since 2016, but the government has issued several environmental regulations to dismantle illegal non compliant activities.

Main ELT management organization: The China Tyre Recycling Association (CTRA) is a national civil organization in China operating on used tire retreading, reuse and recycling. The China Rubber Industry Association (CRIA) is an industrial organization, with a dedicated group for the use of waste rubber.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- Material recovery makes up a significant part of ELT recovery in China. The main determined recovery routes in China are reclaim rubber and granulation.
- ELT material is considered as a resource in China, and all ELT are understood to be collected, though the end use of 61% of used tires remains undetermined.

Impacts on health and on the environment:
- Awareness of the air pollution due to some operations of the pyrolysis industry.
- Some discussion on perceived potential risk of the use of rubber powder in synthetic turf.

Technological innovations:
- Innovative pyrolysis methods with low emissions are in construction.

Opportunities and drivers:
- Government policy enhancing attention to environmental issues.
- Associations pushing for legislative changes.
- ELT generally considered as a resource

Barriers and challenges:
- Most tire manufacturers are small scale and family-owned businesses, not considered prepared to assume responsibility for ELT due to potential costs.
- Considering ELT as a rubber resource in China limits their use in certain recovery routes such as tire-derived fuel in cement kilns.

Europe (ETRMA scope)

Europe (EU, Norway, Serbia, Switzerland, & Turkey)

Europe

ELT data (ETRMA, 2019)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**3425.5**	**100%**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**3035.5**	**89%**
TOTAL Recovered (including Civil Engineering and backfilling)	**3141.0**	**92%**
Sub-total Material Recovery	1855.5	54%
Sub-total Energy Recovery	1180	35%
Sub-total Civil Engineering and backfilling	105.5	3%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**283.5**	**8%**

Data availability and robustness:

Data from recognized source based on robust collection and consolidation methodology. Data for ELT management in Europe is consolidated at the EU level by ETRMA, drawn from a variety of sources (some uncertainty due to estimations/ extrapolations remains). In general, data does not include ELTs from ELVs. Unlike ETRMA statistics for overall recovery rates, this study focuses on ELT rather than Used Tires. Consequently quantities processed through retread, reuse and export are not included in the scope for this study, effectively reducing the recovery rate.

Legal system: Various systems depending on the state. Extended producer responsibility (EPR), free market, or government responsibility financed through a tax.

Major changes in legislation/policy since 2016: Ireland shifted from a free market to an EPR system in 2017.

Main ELT management organization: For physical systems, this depends on the country e.g. France: Aliapur; Italy: Ecopneus; Spain: Signus. For reporting and coordination: ETRMA at EU level.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- Rubber granulates and powder (43%)
- Cement kilns (38%)

Impacts on health and on the environment:
- Studies on the impact of health and the environment continue to focus on the use of crumb rubber on artificial turf and are ongoing. Most recently, the committees for risk assessment and socio-economic analysis of the European Chemicals Agency ECHA adopted and drafted opinions respectively supporting a restriction proposal of the Netherlands to not place granules and mulches on the market if the sum of identified polycyclic aromatic hydrocarbons is greater than 20 mg/kg to further reduce risk of an impact on human health.
- In September 2018, the French research institution ANSES (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail) found that the risk of exposure to granulate in synthetic turf rubber infill was negligible to human health but there was a risk to the environment through transfer of zinc and phenols and that additional measures should be taken in terms of risk assessments and the methodologies of evaluations.
- In February 2017, the EU Chemical Agency published the report "An evaluation of the possible health risks of recycled rubber granules used as infill in synthetic turf sports fields", which concluded that there was a very low level of concern regarding exposure to granules.

Technological innovations:
Innovations and research on advanced ELT technology include projects on efficient pyrolysis technology, use of ELT in asphalt and low noise surfaces, and incorporation of ELT granulate in plastics.

Opportunities and drivers: Circular economy strategies, reputation and brand image, cost reduction

Barriers and challenges: Prices of raw materials, alleged health risks, constraints on innovation

India

India

India

ELT data (ATMA, 2018)	Kilotons (metric) (2015)	Percentage of total ELT generated (2015)
TOTAL ELT Generated (from available sources)	**2749.8**	
TOTAL Recovered (excluding Civil Engineering and backfilling)	**2694.8**	**98%**
TOTAL Recovered (including Civil Engineering and backfilling)	**2694.8**	**98%**
Sub-total Material Recovery	2094.8	76%
Sub-total Energy Recovery	600	22%
Sub-total Civil Engineering and backfilling	0	-
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**55**	**2%**

Data availability and robustness: The most recent data available was provided by ATMA, the main ELT management organization in India, based on a study conducted in 2016.

Legal system: In 2016, the Government of India issued draft Waste Tyres Management Rules. If met with a positive response, the new rules would create a framework for managing ELT practices in a more organized, rigorous, effective and environmentally friendly manner.

Major changes in legislation/policy since 2016: Draft Waste Tyres management rules were circulated among relevant actors.

Main ELT management organization: The main stakeholder is the Automotive Tyre Manufacturers' Association (ATMA), which works alongside the government on potential regulations.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated): Data from 2015 shows that material recovery makes up the large part of ELT recovery (76% of generated ELT), mainly sent towards crumb rubber production.

Impacts on health and on the environment:
- Significant attention given to the negative environmental and health externalities caused by the pyrolysis industry, and governmental action to limit the technology's negative impacts.
- Study launched July 2018 by the State of Haryana's Pollution Control Board, on the impacts of pyrolysis on human health and the environment. Suspension of the installation of new pyrolysis plants in the state until the results of the study are finalized, expected 2019.

Technological innovations:
- ELT in steel production.
- Rubber-modified concrete.

Barriers and challenges: Lack of organized framework around ELT management, limited quantitative information and support from the government, and prevalence of actors involved in the informal ELT recovery sector.

Indonesia

Indonesia

Indonesia

ELT data (APBI/ITMA, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**684.4**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**513.3**	**75%**
TOTAL Recovered (including Civil Engineering and backfilling)	**513.3**	**75%**
Sub-total Material Recovery	376.4	55%
Sub-total Energy Recovery	136.9	20%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**171.1**	**25%**

Data availability and robustness: The data was provided by APBI/ITMA, based on information gathered from large tire collectors but focused on the region of Jakarta and its surroundings.

Legal system: No regulation targeting ELT. It is a free market system.

Major changes in legislation/policy since 2016: There have been no major changes in legislation since 2016.

Main ELT management organization: No particular actors such as public sector actors or trade associations are specifically in charge of ELT Management. However, the Indonesia Tire Manufacturer Association (ITMA), also known as Asosiasi Perusahaan Ban Indonesia (APBI), is involved in the topic.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- Pyrolysis is the main recovery route in Indonesia. It is understood that the primary purpose is to produce oil as TDF for industry.
- ELT is also used as TDF for the manufacturing of bricks.
- 15% of ELT are sent towards material recovery, mainly granulation companies.

Impacts on health and on the environment:
- No research/information on impacts on health and the environment in Indonesia, apart from concerns regarding emissions identified near brick manufacturers.

Technological innovations:
- Material: Studies on rubber-modified asphalt (2018); use of woven waste tires for material reinforcement (2017); soundproof characteristics of reclaimed tire rubber (2016).

Opportunities and drivers:
- ITMA will be initiating discussions with the Ministry of Environment on a potential plan for ELT management.

Barriers and challenges:
- As the country is formed of many islands, this creates logistical issues, and high transportation costs.
- Lack of awareness on ELT recycling at all levels (government, manufacturer, retailer and consumer).

Japan

Japan

Japan

ELT data (JATMA, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**849**	
TOTAL Recovered (excluding Civil Engineering and backfilling)	**780**	**91.9%**
TOTAL Recovered (including Civil Engineering and backfilling)	**781**	**92%**
Sub-total Material Recovery	160.5	18.9%
Sub-total Energy Recovery	619.5	73.0%
Sub-total Civil Engineering and backfilling	1	0.1%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**68**	**8%**

Data availability and robustness: Data provided by JATMA, the main organization involved in ELT management in Japan

Legal system: Free market for ELT, ELT management regulated through the Waste Management and Public Cleansing Act.

Major changes in legislation/policy since 2016: No changes since 2016.

Main ELT management organization: The Japan Automobile Tyre Manufacturers Association (JATMA) monitors and publishes the status concerning ELT treatment, and promotes ELT management. It also carries out research on "production, distribution, consumption and trade" of tires and makes policy proposals concerning "safety and environmental preservation".

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- ELT are mainly recovered as energy in Japan (73%), followed by material recovery at close to 19%. There is only very little civil engineering and backfilling for ELT (0.1% in 2017).

Impacts on health and on the environment:
- No information available

Technological innovations:
- The geographical situation of Japan and its exposure to significant natural events have oriented technological innovations to use ELT as solutions to face these exceptional events (e.g. seawall protections against tsunamis, ground reinforcement in the event of earthquakes).

Opportunities and drivers:
- Favourable legislative context: energy produced from waste or renewable sources is exempted from the reporting and reduction objectives imposed on other energy sources.
- Large demand of ELT for some production uses as tire-derived fuel.

Barriers and challenges:
- Imports of ELT due to the high demand of some recovery routes.
- Small share of material recovery for the valorization of ELT.

Mexico

Mexico

Mexico

ELT data (CNIH, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**467.5**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**95**	**20.3%**
TOTAL Recovered (including Civil Engineering and backfilling)	**95**	**20.3%**
Sub-total Material Recovery	27.9	6%
Sub-total Energy Recovery	67.1	14.3%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**372.5**	**79.7%**

Data availability and robustness: The date was provided by the Mexican Rubber Industry Chamber (CNIH), in units of ELT/Recovery route.

Legal system: ELT are managed according to an official standard, the NOM-161-SEMARNAT-2011, which requires the implementation of an ELT Management Plan, followed by tire producers, manufacturers, importers and exporters.

Major changes in legislation/policy since 2016: There have been no changes in legislation since 2016, though there have been discussions about setting up an EPR system.

Main ELT management organization: SEMARNAT (Secretaria de Medio Ambiente y de Recursos Naturales) is the governmental body in charge of environmental policy-making, and which established the ELT Management Plan. The MRLL (Manejo responsible Llantas Usadas) manages the ELT recovered by the members reporting to SEMARNAT.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- Energy recovery via cement kilns (14.3%) is the major recovery route, followed by material recovery (6%) comprising ground rubber and tire-derived products.

Impacts on health and on the environment:
- Low level of awareness of environmental issues.
- The United States/Mexico border region has been undergoing large clean-up programs.

Technological innovations:
- Rubber-modified asphalt perceived as a promising technology, encouraged by American neighbours (Arizona, California).
- A recycling company developed a line of waterproof construction products, partially made with ELT rubber powder.

Opportunities and drivers:
- Current shared responsibility system and discussions on a potential EPR system.
- Cooperation with the United States for clean-up programs.

Barriers and challenges:
- Large volumes of unauthorized used and waste tire imports into Mexico.
- High collection and transportation costs (inflation in the transport sector and increase in oil prices in 2017).

Nigeria

Nigeria

Nigeria

ELT data (Mathur and Hart, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**113**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**5.7**	**5%**
TOTAL Recovered (including Civil Engineering and backfilling)	**5.7**	**5%**
Sub-total Material Recovery	2.8	2.5%
Sub-total Energy Recovery	2.8	2.5%
Sub-total Pyrolysis	0	0%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**107.3**	**95%**

Data availability and robustness:
There is no national data consolidation or monitoring regarding ELT generation and processing. The figures provided in this table are based on estimations from Vineet Mathur of Infinity Tyres and Sunday Hart of Michelin Nigeria based on domestic tire consumption.

Legal system: There is currently no framework for ELT management in Nigeria and the sector for ELT recovery is informal. However, the Standards Organisation of Nigeria (SON) has been discussing the potential for some form of legislation with producers and importers. This is at a very early stage and only recommendations can be made by SON to the federal government. In addition the National Environmental Standards and Regulations Enforcement Agency (NESREA) has indicated the development of a policy on waste management has reached an advanced stage of progress and that there may be national regulation in the future regarding ELT management in addition to expectations to implement EPR and appoint PRO.

Main ELT management organization: There is currently no ELT management organization.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated): There is no consolidated data for ELT management. However, the following uses of ELT are known to occur:
- Direct Tire Derived Fuel (TDF) for roasting of cattle and goats
- Barriers in schools, carparks and use on marine jetties

Impacts on health and on the environment:
- The potential effects on human health and the environment of using ELT as TDF for roasting cattle and goats has been subject to study with recommendations against the practice.

Technological innovations:
- Multiple studies on the capacities of granulate to absorb oil following spills or other substances.

Opportunities and drivers:
- Discussions between the standardisation body and industry actors showing willingness to develop policy

Barriers and challenges:
- Transportation costs and logistics with regard to infrastructure and the lack of formal collection point or official dumping grounds from which to develop an ELT management system.

Russia

Russia

Russia

ELT data (EcoTyresUnion, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**800**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**160**	**20%**
TOTAL Recovered (including Civil Engineering and backfilling)	**160**	**20%**
Sub-total Material Recovery	154	19.3%
Sub-total Energy Recovery	6	0.7%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**640**	**80%**

*Estimations were 600-1000 killotons of ELT generated in 2014. Interviewee from EcoTyresUnion approximates the current number at 800 kilotons.

Data availability and robustness:
Data from different well recognized sources based on estimations, but remain consistent.

Legal system: The EPR system was established in 2015. The system determines yearly recycling rates to be achieved by tire manufacturers and importers, which can choose to recycle tires themselves, to outsource the activity to recyclers or to pay an eco-tax. They must report their data to the Russian Federal Service for Supervision of Natural Resources Usage.

Major changes in legislation/policy since 2016: The annual quotas are now based on sales rather than production and imports.

Main ELT management organization: EcoTyresUnion, founded in March 2017, unites some of the largest tire manufacturers in Russia, both to guarantee the independent compliance of its members to the ELT obligation but also to represent and protect its members' interests.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- 19.3% of generated ELT are sent for material recovery as crumb rubber or as pyrolysis, though few companies know of pyrolysis and those that use it have trouble with product quality. The remaining 0.7% goes towards energy recovery in cement kilns. In total, 20% of ELT are recovered.

Impacts on health and on the environment:
- No available information

Technological innovations:
- Accelerated pyrolysis method (acceleration from 8-12 hours to 1 hour processing time).
- Material: carbon sorbents from scrap tire (2015), tire reclaimation via depolymerization with nitrous oxide.

Opportunities and drivers:
- The main tire manufacturers in Russia joined the EcoTyresUnion, as a pledge for the sustainable management of ELT.
- The targets defined by the EPR system have been reached.

Barriers and challenges:
- Energy recovery is not considered by the authorities as eligible to meet the ELT management system targets, limiting the potential for ELT energy recovery methods.
- The funds gathered by the eco-tax are not used to further develop the ELT management system.
- There is understood to be potential risk of fraud in the ELT recycling declarations.

South Africa

South Africa

South Africa

ELT data (Redisa, 2016)	Kilotons (metric) (2015)	Percentage of total ELT generated (2015)
TOTAL ELT Generated (from available sources)	204	-
TOTAL Recovered (excluding Civil Engineering and backfilling)	**51**	**24.9%**
TOTAL Recovered (including Civil Engineering and backfilling)	**51**	**24.9%**
Sub-total Material Recovery	41.5	20.3%
Sub-total Energy Recovery	9.4	4.6%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	**153**	**75.1%**

Data availability and robustness: The most recent available data is that of Redisa for activity in 2015. More recent data is only partial in terms of annual operations and would require an extrapolation that appears inconsistent with historic data.

Legal system: From 2012 to 2017, ELT were managed via an EPR system. An interim system is in place since October 2017.

Major changes in legislation/policy since 2016: In the context of a thorough investigation regarding finances, in March 2019 a court cancelled a liquidation order for REDISA, the organisation overseeing the EPR system. During the investigation the government had published a call for new industry waste tire management plans, and had been managing the interim operations during the suspension.

Main ELT management organization: REDISA, an independent non-profit organization was the entity overseeing the EPR system until October 2017. The Department of Environmental Affairs' Waste Management Bureau had been ensuring the interim since then. Since the liquidation order was cancelled, the future management organisation has yet to be confirmed.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- Material recovery is the main recovery route (20% of generated ELT).
- Energy recovery is the second ELT recovery route (5% of generated ELT), especially for TDF in cement kilns.

Impacts on health and on the environment:
- No available information

Technological innovations:
- Two studies from 2018, on the use of recycled carbon black to modify the properties of other materials, and on the potential of solid char, produced via the pyrolysis of ELT.

Opportunities and drivers:
- Establishment of a new waste tire management system, co-designed by all relevant actors (public hearings and consultations on the proposals).
- Strong network of actors previously involved (recyclers, waste pickers) who have renewed their contracts for the new plan.

Barriers and challenges:
- Low global processing capacity in South Africa.
- Concentration of most waste tire processing and recovery facilities in certain provinces, bottlenecks and high transportation costs.

South Korea

South Korea

South Korea

ELT data (KOTMA, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**319.4**	
TOTAL Recovered (excluding Civil Engineering and backfilling)	**280.9**	**87.9%**
TOTAL Recovered (including Civil Engineering and backfilling)	**280.9**	**87.9%**
Sub-total Material Recovery	120.9	37.9%
Sub-total Energy Recovery	160	50.1%
Sub-total Civil Engineering and backfilling	0	-
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	38.5	**12%**

Data availability and robustness: Data provided by KOTMA, the main organization involved in ELT management in South Korea.

Legal system: ELT are targeted by an EPR system as defined in national legislation, which provides a framework for the recycling plans, the roles and responsibilities of actors involved and provisions concerning waste reduction.

Major changes in legislation/policy since 2016: There have been no changes in legislation since 2016.

Main ELT management organization: KOTMA (Korean Tire Manufacturers Association) is a non-profit organization representing the interests of tire and tube manufacturers in Korea. It is the main ELT management organization in South Korea, and its roles include the management, collection and treatment of ELT in Korea, in an efficient and environmentally-friendly manner.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- In South Korea, ELT are mainly valorized for energy recovery (50.1%), and for material recovery (37.9%).

Impacts on health and on the environment:
- The use of ELT in crumb rubber for synthetic turf is restricted by reinforced standards in South Korea and potential incurred costs.
- A study commissioned by KOTMA and its member companies found that none of four major heavy metals considered harmful to human health (lead, cadmium, chromium, mercury) were detected in the lower layer of the urethane tracks analysed.

Technological innovations:
- Interest for rubber-modified asphalt but low demand.
- Material: use of ELT in composites; use of tire chips in bio filters.

Opportunities and drivers:
- Effective EPR system and high recovery rate.
- Government policy limitations on ELT sent to energy recovery (70%) to develop material recovery markets.

Barriers and challenges:
- Current dominance of recovery methods over ELT recycling.

Thailand

Thailand

Thailand

ELT data (Suparat, 2013*)	Kilotons (metric) (2012)	Percentage of total ELT generated (2012)
TOTAL ELT Generated (from available sources)	**515**	
TOTAL Recovered (excluding Civil Engineering and backfilling)	**277.7**	**53.9%**
TOTAL Recovered (including Civil Engineering and backfilling)	**277.7**	**53.9%**
Sub-total Material Recovery	202.3	39.3%
Sub-total Energy Recovery	75.4	14.6%
Sub-total Civil Engineering and backfilling	0	0%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	237.3	**46.1%**

Data availability and robustness:

In the absence of recent robust data, the figures presented above are considered the most recent statistics available.

**Please note that a reference had been misplaced in the report from the last study (2016-17). The year and organisation have since been corrected to was is considered to be the most reliable source available. The data was adjusted following recalculations.*

Legal system: Thailand has a free market for ELT, and the management of ELT is not considered to currently be a priority issue for the government. ELT are not the object of any specific law or regulation, but they fall under the category of solid waste, which is regulated.

Major changes in legislation/policy since 2016: There have been no changes in legislation since 2016.

Main ELT management organization: There is no main organization managing ELT in Thailand, but various actors are associated both from the private and public sectors such as the Pollution Control Department, the Department of Industrial Works under the Ministry of Industry and the Thai Automobile Tyre Manufacturers Association.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated): In Thailand, the estimated recovery rate is of 53.9%. Pyrolysis and cement kilns are the two main recovery routes in the country.

Impacts on health and on the environment:
- There is increasing attention to pyrolysis pollution. Local tire manufacturers highlighted that the industry is expecting the government of Thailand to issue regulations to control operations.

Technological innovations: Developing new technologies to recycle ELT is not considered as a priority in Thailand. However, some studies have been conducted:
- Integration of crumb rubber into cement bricks to lower their thermal conductivity (2013)
- Study of the use of ELT as geomaterials mixed with soil and stabilized by cement for road and embankment construction (2013)

Opportunities and drivers: The government recently commissioned a study on the implementation of a regulatory framework system for ELT management which would: either consist in a tax-based regulation system scheme, or a manufacturer responsibility system, very similar to EPR systems.

Barriers and challenges: Municipalities may lack technical and financial resources to implement recycling projects. Furthermore, there are no official collectors outside of major cities, which can make the collection of ELT difficult in rural areas.

United States

United States

United States

ELT data (USTMA, 2018)	Kilotons (metric) (2017)	Percentage of total ELT generated (2017)
TOTAL ELT Generated (from available sources)	**3700**	**-**
TOTAL Recovered (excluding Civil Engineering and backfilling)	**2668**	**72.1%**
TOTAL Recovered (including Civil Engineering and backfilling)	**2995**	**80.9%**
Sub-total Material Recovery	1227	33.2%
Sub-total Energy Recovery	1442	39%
Sub-total Civil Engineering and backfilling	326	8.8%
TOTAL Other (not-recovered, landfill, stockpiled or unknown)	706	**19.1%**

Data availability and robustness: Data provided by USTMA, the main association relating to ELT management in the United States.

Legal system: ELT are regulated at the state level through federal waste tire management programmes. Each state independently decides on the customer fee imposed on the purchase of new tires, and on potential grants and subsidies for ELT recovery projects.

Major changes in legislation/policy since 2016: There have been no major changes in policy or legislation since 2016, and no major shift expected at the national level.

Main ELT management organization: The United States Tire Manufacturers Association (USTMA, formerly RMA) is the national trade association representing tire manufacturers in the United States.

Main ELT recovery methods, products and applications (expressed as a % of total ELT generated):
- 39% of ELT are sent towards energy recovery in the United States, and 33.2% to material recovery, among which granulation is the main recovery route. In addition, 8.8% of ELT are directed towards civil engineering.

Impacts on health and on the environment:
A relatively high number of studies on health and environmental impacts of ELT recovery methods, especially for the use of crumb rubber for synthetic turf have been conducted in the US.
- Synthetic turf: Significant number of studies conducted within the last 15 years, but results have been inconclusive with regard to potential risk to human health.

Technological innovations:
- Material: Micronized rubber powder; rubber-modified concrete; adsorption of chemical elements using scrap tire rubber, etc.
- Energy: Recovered carbon as anodes for batteries, pyrolysis, etc.

Opportunities and drivers:
- Efficient and well-established ELT management systems.
- Active research into new technologies.

Barriers and challenges:
- Different ELT management methods in each state mean that some states are more advanced than others.
- Regulations can have detrimental effects on the smooth development of some markets (civil engineering, asphalt).

Conclusion of the SOK phase

As expected, the performance of ELT management is generally directly related to the existence/absence and the level of maturity of a formal management system, especially those where one or several actor(s) are dedicated to ELT management (generally associations created by government or tire manufacturers). The older the system (EPR or other) that was implemented, the better the performance is (in terms of collection rate, recycling rate, etc.).

With just over 29.1 million tons (metric) of ELT generated in the 45 countries in the studied scope, approximately 25.6 million tons of ELT are recovered (excluding civil engineering and backfilling but including ELT collected in China with undetermined end use). This would mean that 88% of ELT generated is recovered (90% including civil engineering and backfilling). The market has high-potential for development, especially in countries such as Argentina, Mexico, Nigeria, South Africa, Thailand and Russia, where recovery rates remain relatively low.

Governmental support is crucial in providing the legal framework in which the ELT markets can be developed. Moreover, as they can affect public health, allow the development of new industries and create employment, there is an even greater expectation for local governments to drive ELT recovery markets and control illegal ELT generation and treatment. Setting the status of ELT is one of the first steps taken by local regulations, defining it as product or a form of waste and determining potential for import or export and the logistics of land transported ELT since, when considered waste, some countries require transportation companies to have a specific permit (e.g. Italy).

According to the information collected during this study for the 45 countries (13 countries around the world and the 32 countries of ETRMA scope for Europe), 97% of the ELT recovered with a determined end use are processed through material recovery and energy recovery. Although TDM and TDF are rather well spread at the global level and used as major recovery routes in a large number of countries, the production of reclaim rubber is mainly developed in Asian countries such as China and Thailand. This is the main recovery route in China (34% of the total domestic recovery market) that represents about one fifth of the total ELT recovered (including civil engineering and backfilling) for the selected scope.

The remaining portion of the market is mainly shared between pyrolysis & gasification and civil engineering & backfilling. Pyrolysis is one of the more important recovery routes in Indonesia and Thailand, while it remains very marginal in other countries. The market for civil engineering and backfilling is concentrated in certain countries and regions: Brazil, the USA and a few countries in Europe. In particular, it represents 9% of the domestic market in the USA.

Part II: Feasibility evaluation

The second part of this report consists of the results of the second phase of this study, which aims to evaluate the feasibility of a selection of recovery routes through the associated methods, products and applications. The following technologies were identified for the feasibility evaluation (in alphabetical order) as major categories of ELT recovery:

- Cement kilns and other energy production (e.g. power plants, boilers and more);
- Civil engineering (e.g. of applications: barriers, embankments and more);
- Reclamation;
- Granulation (e.g. of applications: rubber-modified asphalt, artificial turf infill, molded rubber products and more);
- Pyrolysis; and
- Steel production.

The recovery routes above are presented in Figure 6 below.

The feasibility evaluation was conducted based on analysis in relation to multiple criteria across four main categories:

- Regulatory context;
- Technical feasibility;
- Economic drivers; and
- Sustainability considerations.

This report is then structured into chapters that highlight, compare and contrast between current situations and future trends facing recovery routes across each of the four categories listed above, followed by summaries of the individual feasibility evaluations of recovery routes and associated ELT applications.

Methodological approach

As identified in Figure 6, it is important to note that where safety standards on a tire's useful life are respected, retreading and reusing tires before they are disposed of as ELT can be considered to promote circular economy as aligned with the waste management hierarchy. However, this study focuses on ELT, at the point at which the useful life of the tire is complete and it is deemed to no longer serve its intended function.

The results of the study presented in this report are based on information collected via literature review and interviews with stakeholders.

A stakeholder mapping has been performed in order to include key stakeholders in our data collection and consultation process.

We would like to thank all of those who kindly participated in the study, through interviews or by other means, supporting the completion of this project.

Methodology on data collection, consolidation and limitations

As stated in the introduction, the information presented in this chapter has been collected through two main approaches:

1. Literature review such as public studies, public databases and statistics, academic studies, existing and emerging regulations, etc.
2. Stakeholder consultation process based on interviews. In some cases, mainly for language barriers, the information was collected via written feedback after an interview guide was sent to the interviewee.

The following is NOT considered as ELT and will therefore be excluded from data: retread tires, second-hand tires and tires exported with used cars. This change in scope is the main reason why some of the recovery routes communicated in the study may vary from the source data.

The ideal target scope for this study includes all types of tires: passenger car, truck, airplane, agricultural, two and three-wheel as well as OTR tires. Nevertheless, the data presented hereafter is limited to the scope of each source of data found. Passenger cars, bus tires and truck tires are included in all of the country/region data (these are the most significant quantities in terms of units of ELT generated). OTR tires (an important category because of the significant weight per tire) and the other categories are not always included in the source data.

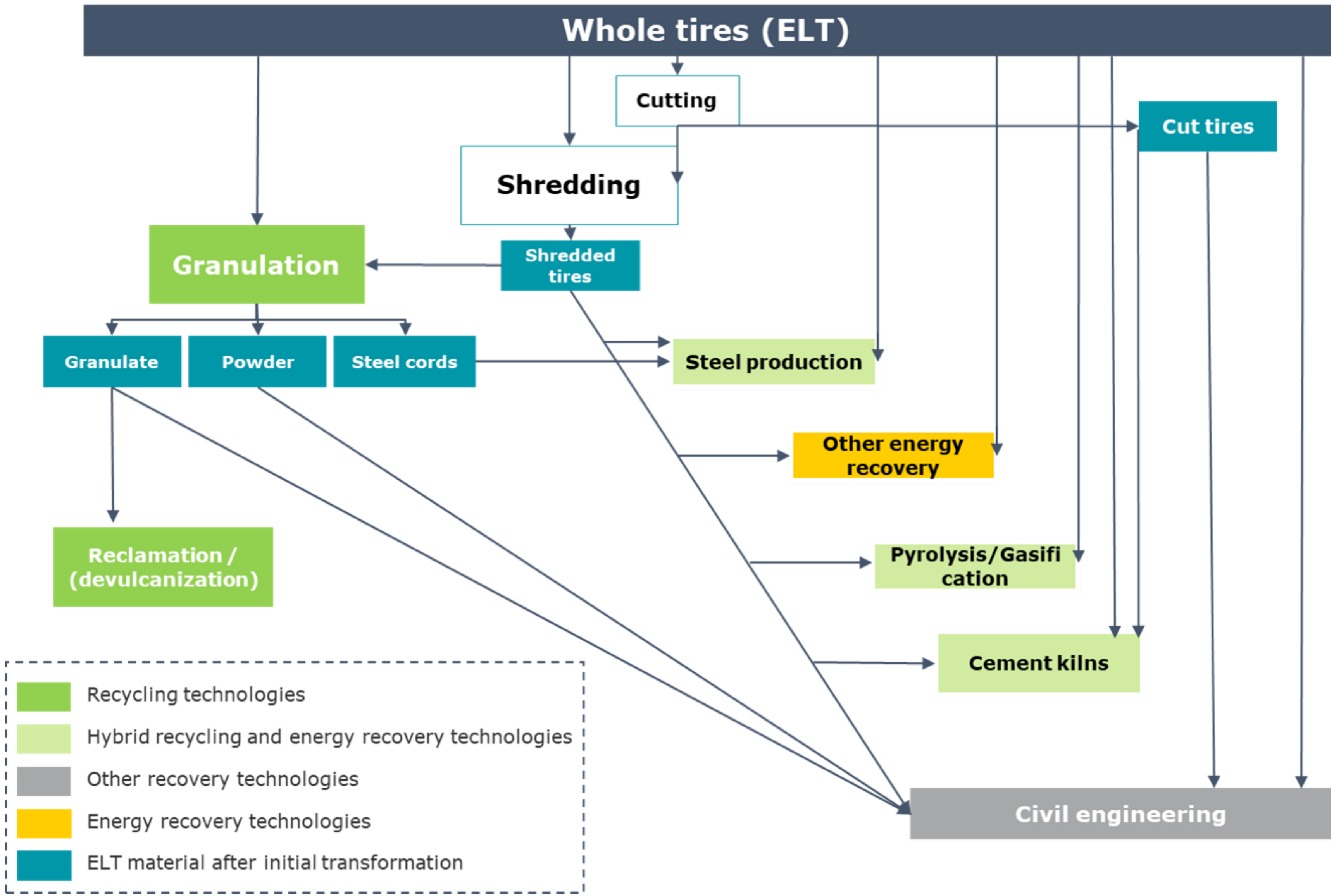


Figure 5 Illustration of non-linear links between recovery routes (initial stages of transformation pre-application)

Scope of the feasibility evaluation

The following section presents the results from the feasibility assessment, which covered seven recovery routes and ten recovery applications. Findings from the Phase 1 SOK helped identify the major ELT recovery routes, while the applications were determined based on a number of factors, including their importance in volume, their potential for further development and the information available for each application.

However, recovery applications differ widely between countries, especially with regards to their technical and sustainability characteristics. The maturity of specific technical processes differs from one region to the next, and many separate processes can exist for a single application.

The evaluation carried out in the following section is built on the information that was available within the scope of this study.

Recovery route	Recovery applications assessed
Granulation	Artificial turf infill
	Playgrounds
	Rubber-modified asphalt
	Rubber-molded products
Reclamation	Reclamation
Pyrolysis	In the absence of specific applications, the feasibility assessment was conducted on the entire recovery route.
Cement production	In the absence of specific applications, the feasibility assessment was conducted on the entire recovery route.
Steel production	In the absence of specific applications, the feasibility assessment was conducted on the entire recovery route.
Civil engineering	This recovery route was assessed as one application, due to the similarity of civil engineering applications in terms of regulatory, economic, technical and sustainability considerations.
Other energy recovery	In the absence of specific applications, the feasibility assessment was conducted on the entire recovery route.

Table 3: List of recovery routes and applications assessed for the feasibility evaluation, and key sources of information

Regulatory frameworks of ELT recovery routes

Overview of the regulatory context around ELT recovery routes: In terms of regulation, some recovery routes are directly subject to regulation at the national or at larger levels (e.g. EU level), while other methods are indirectly affected by rules imposed on other recovery routes.

A key element to highlight is the dichotomy (with some hybrid cases) between material and energy recovery, which appear throughout different policy measures, though these are strongly linked to the geographical area considered.

In areas where ELT management systems had to deal with historical stock piles, illegal landfill or dumping issues, TDF markets could be strongly encouraged by the government as a clean and efficient way to start in order to manage ELT. In addition, with increased environmental awareness and strengthened regulations on energy consumption and greenhouse gas (GHG) emissions, ELT prove to be an attractive alternative fuel to use. In Japan, the government has set up exemptions to reporting and reduction objectives for energy produced from waste or renewable sources.

In countries or regions with a more mature ELT management system, the use of ELT for energy recovery, which involves the combustion of tires, can be discouraged, capped or even forbidden to favor material recycling in line with a waste management hierarchy (energy recovery is positioned low in the waste hierarchy, and can be considered close to disposal).

Concrete examples of the limitations posed to energy recovery include:

- The European Waste Framework Directive 2008/98/EC which favors material recovery over energy recovery;
- The prohibition of waste material combustion, including ELT, to encourage the use of waste for higher-value markets in several Canadian provinces (OWNA, 2017);
- The absence of funding to expand the tire-derived market or to carry out studies about energy recovery in California; and
- The Russian EPR system, which excludes some recovery methods (namely cement production, steel production, energy generation and pyrolysis) to achieve yearly ELT recycling targets.

Material recovery methods, including granulation and reclamation, are in many cases considered as priority recovery routes.

Regulation specific to some recovery applications: Some pieces of regulation have also specifically targeted certain applications of ELT recovery, such as rubber-modified asphalt or artificial turf infill.

For instance, while controversy has arisen regarding the use of ELT in artificial turf infill, no regulation limits the use of this material as of 2019, except in South Korea, where the use of ELT as rubber granulate for synthetic turf has been restricted by reinforced standards (KS F 3888-1).

Financial perspective linked to regulation: subsidies, grants and taxes: The same dichotomy between material and energy recovery is expressed in terms of subsidies: many subsidies were identified for the use of granulate in high value applications (e.g. rubber-modified asphalt, devulcanization, etc.).

It is understood that there are very few subsidies available for cement industries using ELT, and the only case identified was in Japan. However, gate fees also have an influence on the use of ELT in cement kilns. In South Africa for example, some cement companies stopped using ELT in their kilns after gate fees supported by policy were removed for ELT, which made this waste stream no longer financially interesting for the cement industry (Doyen, 2019).

According to Barry Takallou, CEO of CRM a tire recycling company based in the USA and Canada, despite the need for subsidies to establish markets for recycled crumb rubber products, market-push tire recycling programs that provide incentives to the manufacturers can be considered as a form of artificial intervention by the government in the market place that can distort the true demand, potentially resulting in anti-competitive behavior, fraud, and dependency on incentives, as well as dumping of overproduced products that could force recycling companies out of business (Takallou, 2019). However, in a market-pull tire recycling program, the principle is that incentives are given to end users of the recycled tire products to develop local sustainable markets (Takallou, 2019).

Finally, grants can be awarded to innovative and developing technologies, which promotes research for new forms of recovery routes.

Regulation targeting environmental protection or safety: While many of the above regulations concern waste management and various applications of ELT recovery, more and more importance is given to the impacts of various recovery routes on the environment.

The risks posed by various recovery routes or methods in terms of human health are of utmost importance to public authorities. For example, measures are being taken by the government and the industry in China to move away from polluting reclamation methods by providing subsidies for cleaner methods.

The compliance with or promotion of a waste management hierarchy is a common trend in many of the regulatory frameworks assessed in this study. Some regions or countries have set objectives to encourage recycling and limit energy recovery, while others have established more stringent regulations to exclude energy recovery from ELT management systems. Many countries have yet to establish a clear framework for ELT management resulting in the establishment of informal systems.

Technical feasibility of ELT recovery routes

The recovery methods, products and applications that make up the routes covered in this evaluation use a wide range of technologies even within a particular family of approaches to ELT management, where there are significant gaps between standard and advanced forms.

Granulation processes are historically well developed with a variety of different applications, some being more significant than others. These processes do not present major technical difficulties. This factor is equally if not more applicable to civil engineering applications, which involve limited processing or transformation. While reclamation has existed since the 1960s, some new innovative devulcanization processes are less than a decade old, but both are at stages of commercialization.

ELT have many technical properties (e.g. lightweight, thermal insulation etc.) that are suitable to civil engineering applications, however supply does not always meet demand in terms of required volumes for large scale projects. The capacity of large facilities such as power plants and cement kilns is also another opportunity to treat stockpiles in the short term. However, adaptations are required to support the use of ELT in these facilities.

Some applications of granulation are considered to be more technically advanced than others. The output products are usually of high quality and those applications that are more innovative will focus on higher added value products such as micronized-rubber powder.

In most cases, the main products of recent devulcanization techniques aim to be used in tires, while reclaimed rubber can be used in a wider variety of products albeit with limited added value such as in tubes, liners, cables or tiles and also in new tires, although the quality has been considered limited at the current stage of technological development for the latter.

There is a similar discrepancy for different pyrolysis technologies. Overall, efficient technology producing high quality outputs are not widespread. In parts of Asia the fundamental process of pyrolysis is in operation on a large scale, largely for the production of oil as TDF. However, research and development with some projects at commercial scale are underway for example on high quality carbon black and oil output products for which significant pre-processing and post-processing measures are required.

Barriers to entry have been observed in particular for countries with less mature ELT management systems due to the lack of funds to invest in high volumes and adequate technology (see economic drivers section).

The attention to quality for an existing process or product is key for industries that incorporate ELT as a replacement for fuel or material. The technical feasibility is generally positive for the use of ELT material in steel production thanks to the significant portion of steel in the tire and the capacity for ELT to replace anthracite to provide carbon. However, attention must be given to the composition and chemical balance to maintain the quality of the process and product. In cement kilns, and energy generators, the use of shredded tires is preferred or required due to the enhanced ability to dose the material to avoid detrimental impacts on production conditions. Adaptation of equipment and infrastructure and testing of processes for the replacement of traditional fuel with TDF will also be necessary to begin with but the ELT material is considered relatively stable.

It is worth noting that the composition of tires is relatively stable. This is a cross-cutting factor that supports most recovery routes and TDF in particular when compared to some municipal solid waste for instance.

In conclusion, the technical feasibility of the recovery routes differ based on a number of factors, among which their stage of development, their capacity to absorb large volumes of ELT and the quality of output products. Some methods are well-developed, without any technical difficulties, while others involve very complex processes. In some cases, one single recovery method can involve several separate processes (e.g. reclamation, devulcanization, pyrolysis). Finally, while certain methods absorb large volumes of ELT, others have given more priority to the production of high-quality products, despite the absorption of lower volumes.

Economic drivers for ELT recovery routes

The economic drivers of recovery routes are determined by various costs, opportunities and market conditions. Certain recovery routes depend on the value added of output products using ELT as feedstock (material recycling in particular) while others replace traditional materials or fuel with ELT.

A number of cross-cutting factors may affect all recovery routes, including capital costs associated with storage, fire protection, infrastructure with varying degrees of necessary adaptation for existing facilities. Transportation and logistics can also result in major running costs depending on the ELT management system in place and the supply chains established.

The backlash against pollution may be restricting the economic drivers for reclaimed rubber, which has been a historically strong market in certain geographical zones, including China. Despite its current importance, this market is expected to be constrained in coming years due to restrictions imposed by local authorities related to the potential environmental impacts of chemical reclamation in particular.

Among the different recovery routes are those that involve minor adaptation of current facilities used for particular purposes and others that are established for the purpose to be dedicated to recovering TDF or TDM from ELT. The capital expenditure and operational expenditure required for the latter ELT recovery facility is of course more significant.

For example, the economic model for granulation and its applications with value added products may require relatively high investment costs on equipment and infrastructure than what is needed for other recovery methods, as granulation can entail advanced treatment and processing stages. The granulation industry is dependent on gate fees in some areas. The low prices at which granulate is sold for playgrounds or artificial turf for example creates a need for gate fees to support the activities of granulators (Domas, 2019).

The use of rubber granulate in playgrounds or artificial turf infill represent some of the key applications for granulation. However, one ton of the material ELT rubber replaces, which is ethylene propylene diene monomer (EPDM) rubber, can be sold for almost 7 times as much as ELT material. The large difference between the two and the smaller revenue generated by sales make some granulators dependent on gate fees (Domas, 2019). However, the market for playgrounds has seen a steady increase over the past decade, as opposed to that of artificial turf infill which has witnessed a drop in certain European markets due to negative public perception (Raahauge, 2019).

The development of high value products using innovative technologies in stages of processing can be a way of compensating for these capital and operational expenditures. On the other hand, rubber-molded products generally have less added-value, and the industry has been perceived as being dependent on subsidies where available.

On a global scale, economic drivers of pyrolysis are currently low due to the competitiveness of the products in relation to virgin or traditional materials. This is based on both price and quality. Overall the added value compared to these materials is low and the cost to produce them can be high. The profitability depends on the added value of the output product. The trend for further development is positive for pyrolysis. One output, carbon black, derived from ELT is currently in the process of being commercialized by a small number of companies for different applications and there appears to be potential for growth.

Multiple specific factors play a role in determining the economic drivers for applications. Some markets for applications of granulation have fallen in significance in recent years. The market for artificial turf infill fell by 30% in volume of ELT consumed between 2014 and 2017 in the USA due to public and industry perception (see sustainability section) and saturated markets.

Despite advantages in cost and durability, the market for rubber-modified asphalt has historically been limited by regulatory barriers linked to competition with traditional materials combined with industry reluctance to change, which also hinder its commercialization.

Although the market for civil engineering applications of whole or shredded tires remains small, with applications serving different purposes, these applications are often less expensive than traditional alternatives, and their implementation and processing costs are not considered as being limiting factors to economic viability. As with rubber modified asphalt, using ELT in civil engineering also creates products with a high added value, thanks to the advantageous technical properties of ELT.

For more innovative recovery technologies, there is some room for expansion of output products to new sectors for example devulcanized rubber and for granulation, innovative technologies focused on high quality output material.

Concerning TDF, the price of traditional fuels is critical for the competitiveness of ELT. Figures 5 and 6 show the changes in coal and oil prices over time. After a peak in 2011 followed by a dip until 2016, prices started to climb again. Under current circumstances, TDF has potential to be particularly competitive. It is important to note that the price of ELT varies across different countries and at different stages of the value chain. However, TDF is usually five to ten times less expensive than coal or petcoke, and represents major savings for the cement or other energy industries (Domas, 2019). This factor also concerns steel production and the replacement of anthracite.

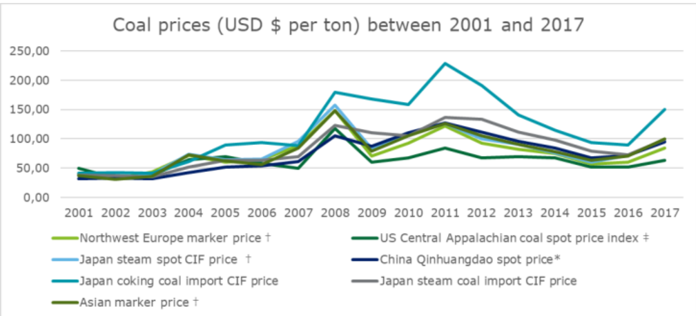


Figure 5: Graph showing changes in prices of coal over time. Source: BP Statistical Review of World Energy

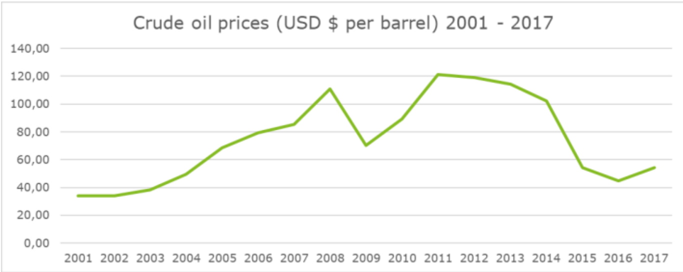


Figure 6: Graph showing changes in prices of crude oil over time. Source: BP Statistical Review of World Energy

Although other alternative fuels, including solid recovered fuel, may lead to greater competition for ELT stable ELT composition and high calorific value makes it a relatively appealing option (see technical feasibility section).

For material recovery, in particular reclaim rubber, over the past few years, the price of both natural rubber and synthetic rubber has been on the decline. According to the International Rubber Study Group (IRSG), the price of one ton of natural rubber was US$ 2,635[4] in 2013, falling to US$ 1,207 in 2016. In 2019, the price of natural rubber usually revolved around US$ 1,800 per ton (Global Rubber Markets, 2019). Nevertheless, the price of reclaim rubber is still significantly lower, at approximately 30% of the price of natural rubber (Gandhi, 2014). In addition, the price of reclaim rubber has remained relatively constant, only slightly increasing in recent years, compared to market volatility characterizing the prices of natural and synthetic rubber (GRP 2014).

A cross-cutting factor identified that can make up part of the financial transaction is the availability of gate or tipping fees particularly for industries that do not produce high value products including TDM and TDF. Depending on the output product and its market value, recyclers in different countries around the world are willing to pay between $5 USD and $100 USD per ton for ELT material, with an average of around $50 USD per ton.

Overall, the long-term context in a particular location must be assessed to evaluate viability taking into account the factors identified above and the significance of their impact.

[4] Based on the average of the prices for SGX RSS3, SGX TSR20, and Europe TSR20

In conclusion, a distinction is to be made between recovery routes which depend on the added value of output products using ELT as feedstock (material recycling in particular), and those that replace traditional materials or fuel with ELT. The economic model for several granulation applications may require relatively high investment costs for equipment and infrastructure, while the economic viability of other applications will depend on the price of the traditional counterpart (e.g. fuel). The market size must also be considered, as there appears to be room for new technologies, offering innovative products, while the market for certain traditional applications, such as granulate used in artificial turf infill, has decreased.

Sustainability considerations relative to ELT recovery routes

Position in waste management hierarchy: The recovery routes and applications assessed in the scope of the study do not all have similar positions along the waste framework hierarchy, which considers the following preferred order to manage waste:

- Prevention;
- Re-use;
- Recycling;
- Recovery; and
- Disposal.

The positions of the different recovery routes and the associated applications are illustrated in Figure 7 below.

As seen from Figure 7, two recovery routes are positioned in the recycling category: granulation and all of the applications associated (e.g. rubber-modified asphalt, artificial turf infill, molded rubber products, etc.) and reclaimed rubber, which also involve material transformation to form reclaimed rubber.

Meanwhile, three recovery routes are split between material and energy recovery and are considered as hybrid technologies in the scope of the project: pyrolysis and gasification, the use of ELT in cement kilns, and the use of ELT in steel production. All three of these technologies contribute to material recovery. Pyrolysis for example generates char in addition to oil and gas. The iron that is released during the burning of tires in cement kilns is used as material in the composition of cement. ELT can replace anthracite in steel works to provide carbon and prevent oxidation of metal. Civil engineering, makes use of whole tires or tires recovered through processing to varying degrees although transformation is generally considered limited for this category.

Finally, only the wider group of energy recovery, which comprises the use of ELT in power plants, industrial boilers or pulp and paper mills, does not contribute to material recovery. This recovery route is considered as "Other energy recovery" and is not a priority route according to the waste management hierarchy.

WASTE HIERARCHY	REUSE	RECYCLING		OTHER MATERIAL RECOVERY	RECOVERY HYBRID			ENERGY RECOVERY	DISPOSAL
ELT INPUT	**Whole tires**	Whole or Shredded tires	Rubber granulate	Whole or Shredded tires, Rubber granulate, Crumb rubber and Powder	Whole or Shredded tires	Whole or Shredded tires	Steel cords, Whole or Shredded tires	Textile, Whole or Shredded tires	**Whole tires**
MANAGEMENT METHODS	**Repairing** **Regrooving** **Retreading**	**Granulation and associated applications**	**Reclamation**	**Civil engineering**	**Pyrolysis and gasification**	**Cement Kilns**	**Steel production**	**Other energy recovery**	**Landfill** **Incineration**
PRODUCTS (OUTPUT)		Granulate and powder	Reclaimed rubber	N/A	Oil, gas, carbon/char, steel				
APPLICATIONS		▪ Artificial turf infill ▪ Athletics tracks ▪ Molded rubber products ▪ Playgrounds ▪ Roofing material ▪ Rubber-modified asphalt	▪ Inner tubes ▪ Insulation tiles used in public transportation for reducing the noise level ▪ Tiles for laying pedestrian concrete areas ▪ Tubeless tire liners	▪ Agricultural use ▪ Baled tires ▪ Breakwaters ▪ Coastal protection ▪ Erosion barriers ▪ Ground improvement ▪ Landfill construction operations ▪ Road embankments ▪ Shelters ▪ Slope stabilization ▪ Sound barriers, insulation applications	Carbon black: industrial gaseous effluents treatment (e.g. mercury, suplhur dioxide) Char: water and purification Oil and gas: TDF			Alternative or additional fuel for energy generation in: ▪ Brick production ▪ Industrial boilers ▪ Power plants ▪ Pulp and paper mills ▪ Waste-to-energy plants	
EXAMPLES OF ADVANCED TECHNOLOGIES		▪ Absorption of phenol and oil in water ▪ Composites ▪ Concrete ▪ Micronized rubber powder ▪ Porous pipes from recycled ELT	Reclamation by depolymerisation by nitrous oxide	▪ Retaining walls ▪ Soft clay reinforcement	Use as anodes in lithium, potassium and sodium-ion batteries	N/A	N/A	N/A	

**The waste hierarchy category "Reduce" is not in the scope of this analysis. In addition, "Reuse" has been included, however this is not applicable to all tires and would depend on the condition of the product in relation to the appropriate safety standards.*

Figure 6 Position of recovery methods and applications along the waste management hierarchy

Environmental considerations illustrated by life cycle assessments (LCA): The sustainability considerations relative to ELT recovery applications were assessed through various indicators in the scope of LCA studies.

The recovery of ELT for use in various applications is usually always environmentally preferable to traditional alternatives. The production of synthetic turf, the manufacture of molded products and the use of ELT in cement kilns stand out as the most advantageous methods on the basis of a selection of environmental indicators in a study conducted in 2010, including total primary energy consumption, water consumption and production of waste (Aliapur, 2010). The environmental performance of playgrounds is very similar to that of artificial turf infill, as the materials replaced by using recycled rubber are the same for both applications. In comparison, the environmental performance of civil engineering applications and retention and infiltration basins are relatively minimal.

The benefits of ELT recovery and of its different applications generally result from using ELT as substitutes for high energy-consumption materials (such as EPDM for artificial turf or molded products) and from avoiding the production and transport of certain substituted materials when the life span of ELT products is greater than those of the products they replace (Aliapur, 2010).

The high environmental performance of cement kilns and artificial turf was also illustrated in a number of other studies. The use of ELT in cement plants and in artificial turf provides reductions in GHG emissions, air toxics, and water consumption. The substitution of one ton of coal by TDF avoids an estimated 543 kg (CO_2 equivalent) of direct and indirect GHG emissions (Fiksel, 2011).

However, the use of ELT in artificial turf infill was already facing barriers back in 2011 because of market saturation. Currently, this market is even more limited due to recent controversy (Fiksel, 2011).

Results from LCAs tend to depict rubber-modified asphalt as an application with lower environmental benefits than the other recovery methods and applications considered in the study. Indeed, asphalt production involves additional processing steps for ELT granulate that may require high electricity and diesel consumption, with associated GHG emissions. However, rubber-modified asphalt still represents a very interesting application of ELT as it can be recycled, unlike most granulation applications. Rubber modified asphalt has been shown to improve the performance and durability of the pavement surfaces stream (Takallou, 2019). Moreover, it can be recycled multiple times at the end of its service live (Takallou, 2019). Many, rubber molded products, however, eventually end up in the landfill and would therefore in comparison be considered only to delay the waste stream (Takallou, 2019).

This trend was confirmed in a study carried out in 2017, indicating that rubber-modified asphalt did not show high environmental performance in terms of acidification, global warming potential, and depletion of abiotic resources for instance. The uses of liquid asphalt, gravel, and diesel in the process are considered key factors (Ortíz-Rodríguez et al., 2017).

Meanwhile, particular applications were also compared one-on-one, with comparisons of the environmental performance of material recycling (where ELT were sent towards artificial turf and asphalt) and both cement kilns and civil engineering applications.

Material recycling was found to have more environmental benefits than co-incineration, with major differences in terms of global warming potential, energy demand and acidification. For instance, between 0.07 and 0.31 person equivalents[5] are saved per ton of tires being recycled and not incinerated. If 650,000 tons of ELT (representing Germany's annual ELT production in 2009) were sent towards recycling instead of incineration, this would represent annual potential savings of between 40,000 and 200,000 person equivalents, depending on impact category (Kløverpris et al, 2009a).

Meanwhile, 570,000 tons of CO_2 emissions (corresponding to annual emissions from more than 50,000 Europeans) could have been saved if the annual amount of tires being sent to civil engineering applications in Europe in 2009 (300,000 tons) had been

[5] Person equivalents express the total impact of treating one ton of ELT relative to the total environmental impact caused by one person in one year.

used for material recycling instead (Kløverpris et al, 2009b).

Overall, material recovery routes were found to have the best environmental performance out of the applications assessed throughout LCAs. The use of ELT in cement kilns also shows high environmental benefits. The findings of separate studies are not comparable from one to the other, as the hypotheses made and the methodologies applied differ. It is also important to note that little data is available for some of the recovery routes and associated applications covered in this study, for example devulcanization, reclamation, pyrolysis, as they are still quite new methods.

Focus on some applications and innovative technologies: The following section provides a focus on the environmental performance of a selection of ELT recovery applications, for which quantitative information was available.

In the case of micronized-rubber powder production, which uses cryogenic granulation, current processes can release half the amount of CO_2 compared to traditional synthetic rubber manufacturing. The product is cooled using liquid nitrogen and therefore does not require water. Overall, the process can generate savings of 10kWh compared to the production of 1kg of synthetic rubber (Lehigh technologies, 2019).

Producing carbon black from tires during pyrolysis avoids its production through traditional methods, in which oil is the primary feedstock. For every kilogram of carbon black produced through ELT pyrolysis, around 5 kg of CO_2 are saved in relation to carbon black produced using oil (Cardozo, 2019). CO_2 eq. emissions reduction is hence generally above 80% compared to virgin carbon black production, which is also an economic factor when carbon pricing is applied (Ershag and Olofsson, 2019).

Finally, in terms of sustainability considerations, different devulcanization processes involve considerable environmental benefits compared to the production of a typical tire compound. Some processes consume low amounts of energy to convert ELT rubber crumb into devulcanized rubber compound. The total energy consumption for the production of ELT crumb and subsequent devulcanization represents 94% of energy savings compared to the energy required to produce virgin tire rubber compound (Visaisouk, 2019).

Potential risks to human health: Overall, the majority of studies have concluded that the recovery of ELT implies little or no risks for human health, except for some recovery methods and applications detailed below.

The use of ELT in artificial turf infill is a controversial ELT application due to perceived risks for human health. Many studies on the topic are still underway, in the USA and in Europe for example. In 2017, the European Chemicals Agency (ECHA) concluded that there was “at most, a very low level of concern from exposure to the granules” found in sports pitches and playgrounds (ECHA, 2017). As of 2019, the studies published on this topic indicate that there is very low or no risk for human health associated with the use of ELT in artificial turf and playgrounds.

For instance, Anses, the French Agency for Food, Environmental and Occupational Health & Safety, reviewed over 50 international studies on the potential health and environmental risks associated with artificial turf and playgrounds using recycled rubber. The main conclusions from the review indicate low concentrations of heavy metals, plasticizers, additives and volatile organic components (VOCs), all below reference toxicological values, in artificial turf infill and playgrounds. Given the low concentrations of carcinogens emitted or released by tire granulate, the studies consider the risk of carcinogenicity as low or negligible[6]. The study did however identify potential risk to the environment, through the transfer of zinc and organic substances such phenols or phthalates. However, the current SOK on this subject was not sufficient to draw any conclusions (Anses, 2018).

Furthermore, ETRMA published a statement on the safety of recycled rubber infill material in 2016. Rubber components which can come into direct contact with the general public must comply with EU REACH restrictions (ETRMA, 2016). According to the analyses conducted and rubber chemical registration dossiers submitted as well as the reactivity of used chemicals, “no known CMR [carcinogenic, mutagenic, or toxic for reproduction]

[6] PAHs constitute the carcinogenic substances most frequently evaluated in the studies analyzed.

substances are present in the granules in concentrations equal or greater than either the relevant specific concentration limit specified in Part 3 of Annex VI of Regulation (EC) No 1272/2008, or the generic concentration limit" in Part 3 of Annex I of the same regulation (ETRMA, 2016). Many of the 70 scientific reports and articles published worldwide by the time of writing of the ETRMA statement in 2016 concluded that. "there is no significant or scientifically justified risk associated to the use of rubber granules made from end of life tires" (ETRMA, 2016).

There have also been concerns around the harmfulness of burning waste in cement kilns on human health due to air pollution. It was concluded that the risk to human health is minimal.

For other recovery routes, the wide array of technologies considered under one route leads to differences in terms of risks associated. For instance, the process of chemical reclamation used in some countries (e.g. China and India) requires large volumes of chemical solvents that are believed to be hazardous to the health of workers, in addition to causing pollution. Furthermore, in India, risks of water pollution and respiratory illness were associated to pyrolysis, and increasing attention is given to the human health risks of this technology in Thailand. However, in Europe, where the pyrolysis processes are very different and involve more advanced technology, there are no significant issues linked to human health at the moment.

Meanwhile, and in relation to the potential risks to human health, some applications of ELT recovery have suffered from negative media perception. The unsubstantiated negative media coverage surrounding artificial turf infill created a difficult decision-making environment for key stakeholders and caused a temporary decline in demand of approximately 30% in the USA between 2014 and 2017 (Bigelow, 2019). Similarly, some civil engineering applications, such as retention or drainage basins, are subject to public mistrust, due to the perceived potential hazardous effects the material could have on water (leaching, etc.). A lack of consensus rests on this matter, though specific studies have been conducted by some companies to demonstrate the absence of risk for water pollution. The use of recycled rubber in playgrounds is not considered as creating risk for environment and health, notably because a top coat covers the layer of recycled rubber in playgrounds (Raahauge, 2019).

In terms of public perception, significant work by cement companies is needed to overcome the perceptions of "black smoke" from open burning (Cumming, 2019). Although the science is well established that emissions tend to be lower with ELT use in high temperature, controlled kiln fuel use there continues to be significant negative press for the use of ELT in cement kilns, affecting brand image and potentially putting off some cement companies from using ELT in their kilns (Cumming, 2019). However, this perception appears to be specific to some geographical areas. In Brazil for example, there does not seem to be negative perception of the use of ELT in cement kilns, especially as it reduces stockpiles and landfill (Bastos Da Porciuncula, 2019). Technologies which are known to have negative environmental and health externalities, such as chemical reclamation, also suffer from bad public perception.

However, some applications or technologies are supported by the public and receive positive media coverage. This is the case for many innovative technologies, such as new devulcanization technologies, granulation methods (which produce micronized-rubber powder for example), or even advanced pyrolysis techniques. Public and industry perception can also be influenced by various contests and prizes, such as sustainability awards. Stakeholders state that winning such prizes has a strong influence on the public perception of their industries.

Lifetime of output products and recyclability: The recyclability of output products is also an important element to take into account when looking at sustainability considerations for recovery methods, products and applications. The information concerning this particular topic was limited, but it seems that most applications of ELT recovery are not recyclable, except for a few exceptions, such as rubber-modified asphalt.

The positive perception of rubber-modified asphalt has improved over the past few years, thanks to the support of tire associations highlighting its potential to improve durability for example (Sheerin, 2018). As aforementioned, it also has the potential for circularity, through recycling by recovery and integration into a new mix where necessary (Takallou, 2019).

In conclusion, the sustainability considerations relative to ELT recovery routes can be assessed through their environmental performance. Some recovery routes have considerable benefits in terms of avoided impacts according to several LCA studies, such as the use of ELT in cement kilns and in artificial turf infill. Seizing the importance of this issue, new technologies are placing a lot of focus on developing processes with increased attention for environmental considerations, with reductions in energy and water consumptions for example. The impact of these technologies on human health must also be considered, and a wide array of studies have been conducted on those that pose potential risk in terms of environmental and health concerns. Nevertheless, public and industry perception play a crucial role in the acceptance of these technologies, and therefore in the further development and expansion of recovery routes.

Summary for each recovery route

A brief summary of the current state and context surrounding recovery routes is available below in alphabetical order.

Cement production and other energy recovery

Criteria categories	Cement production and other energy recovery
Regulatory context	Overall, where policy promotes material recycling which is generally the case, the regulatory context is not favorable to energy recovery due to restrictions and prioritization. Nevertheless, cement production stands out from this group due to the portion of material recovery comprised in the process. In addition, there are indirect policies that may promote the use of tire-derived fuel (TDF) such as those centered on emissions reductions objectives and the supply of alternative fuel. Although permit procedures may be demanding for large corporations, once this hurdle is surpassed, facilities are adapted for the long term. Economic factors such as gate fees may play a more determining role.
Technical feasibility	The capacity of large facilities such as power plants and cement kilns is useful to treat stockpiles of ELT in the short term. However, despite the fact that it is often possible to use whole tires in cement kilns, the preference of plants is to use shredded tires due to the enhanced facility of dosage. This is considered a prerequisite for other energy recovery facilities such as boilers. Adaptation and testing will also be necessary to begin with but the ELT material is considered relatively stable.
Economic drivers	The economic drivers of the use of ELT in cement kilns depend on a number of factors. Favorable circumstances for the use of ELT include gate fees and relatively high prices for traditional fuels. Although other alternative fuels including solid recovered fuel may lead to greater competition, stable ELT composition and high calorific value makes it an appealing option. Some investment on infrastructure and adaptations are required. Consequently the long term context in a particular location must be assessed to evaluate viability. Overall the outlook is most positive for cement kilns where there is a gate or tipping fee.
Sustainability considerations	Industries can switch from fossil fuel to ELT for a share of their energy needs and generate less greenhouse gas (GHG) or other polluting emissions. Alternative fuels, including TDF, are therefore useful for industries to decrease air pollution, and to comply with environmental regulations and improve overall sustainability performance. Some negative public perception has been observed in places with well-established ELT management systems in particular. Cement kilns stand out on top above other recovery routes thanks to additional replacement of energy intensive extractive material and lack of extra generated waste by default. Connected to the CO_2 reduction, the material recovery impact is enhanced by the biomass content (natural rubber) of the ELT.

Civil Engineering

Criteria categories	Civil engineering
Regulatory context	While there are few regulatory frameworks directly applicable to civil engineering, different civil engineering applications may benefit from incentives such as price rebates or subsidies on the purchase of ELT or shredded ELT for use in high value applications.
Technical feasibility	The use of ELT in civil engineering applications does not present any technical difficulties, as its processing steps are the least advanced or demanding of all ELT recovery technologies. ELT have many technical properties (e.g. lightweight, thermal insulation etc.) which make them a very interesting resource that provide high quality civil engineering applications. However, some applications of civil engineering require high volumes of ELT, and the supply of ELT may be difficult to anticipate and to acquire.
Economic drivers	The market for civil engineering applications of whole or shredded tires remains small, with applications serving different purposes. However, these applications are often less expensive than the traditional alternatives, and their implementation and processing costs are not considered as being limiting. Using ELT in civil engineering also creates products with a high added value, thanks to the advantageous technical properties of ELT.
Sustainability considerations	Despite improvements in environmental impacts compared to baseline scenarios (e.g. use of rocks, gravel and sand), the overall performance of civil engineering is considered to be lower than other ELT recovery routes, due to the material that it replaces.

Granulation

Criteria categories	Granulation
Regulatory context	Though few policies or regulations directly target granulation and its applications, this recovery method is indirectly supported through a number of policy measures, as it is considered as a priority recovery route over energy recovery. For example, granulators or industries involved in applications of granulation can benefit from a number of incentives or subsidies on the purchase of their raw material (ELT or crumb rubber). General regulation is therefore in place to either promote applications deemed as having high potential, such as the use of granulate for products with a lot of added value (e.g. rubber-modified asphalt), or to restrict applications considered as potentially hazardous, such as some polluting recovery routes (e.g. reclamation). However, regulatory barriers remain for the use of crumb rubber in rubber-modified asphalt, and this application still faces red tape before it can become more widely used in some countries or states.
Technical feasibility	The granulation process is well developed, and does not present any major technical difficulties, yet some of its applications are more technically advanced. The products are usually of high quality, and those applications that are more innovative will focus on higher added value products, as it is the case for micronized-rubber powder for example. Furthermore, the main constituents of ELT must be separated during granulation (rubber, steel, fibers), which complicates the process and creates the need to find secondary markets for these products. In countries that are less mature in terms of ELT management, many small granulation companies may try to establish themselves, but without sufficient funds to invest in high volumes and in quality technology. In these cases, the barriers to entry for the industry are more difficult to overcome, and it is more complicated to become established as a recognized company.
Economic drivers	The economic model for granulation and its applications may require more investment than what is needed for other recovery methods, as granulation entails advanced treatment and processing stages. Many granulation actors have based their business models on creating high-value products to compensate these high processing costs, and this trend is even more present with emerging innovative granulation technologies. On the contrary, rubber-molded products have a small added-value, and the industry was perceived as being highly dependent on subsidies. Some markets for applications of granulation have fallen in significance: the market for artificial turf infill fell by 30% between 2014 and 2017 in the USA, and the market for rubber-modified asphalt is still limited by regulatory barriers, which also hinder its commercialization. Meanwhile, the market for playgrounds has been steadily growing over the past decade. Innovative technologies are now opening up new markets for granulate, crumb rubber or rubber powder, expanding the possibilities for these products.
Sustainability considerations	In terms of sustainability considerations, there is a reduction of environmental externalities for most of the applications of granulation that are assessed. All of them show benefits in terms of the use of resources, supported by a number of life cycle analyses. Granulation is also considered as material recovery, and is high up in the waste management hierarchy. Some applications may be selective in terms of input material (type and quality of ELT), which implies that ELT that are refused at arrival, and sent towards less selective recovery routes, such as cement kilns. Finally, while most products are well-perceived by society, artificial turf infill has suffered from a negative public perception, due to perceived health and environmental hazards, causing a drop in the market. However, over the past ten years, the multitude of studies conducted have indicated very low or no risk associated with the use of ELT in artificial turf or playgrounds.

Pyrolysis

Criteria categories	Pyrolysis
Regulatory context	Generally, as a significant portion of the output products of the pyrolysis process can be categorized as tire derived fuel, it is not always supported by waste management policies. In addition, the environmental impacts of operations have been under particular scrutiny by authorities. The recovery route is particularly common in the informal sector, where there is a lack of controls. On the other hand, grants may be available to support further development of innovative aspects of enhancing the added value of products such as carbon black. The specificities of these innovations are often protected by intellectual property rules, which may limit competition.
Technical feasibility	Overall, efficient technology producing high quality outputs are not widespread. In parts of Asia the fundamental process of pyrolysis is in operation on a large scale, largely for the production of oil as TDF. However, more trials and pilot projects are taking place across the globe with some at the beginning of commercial scale. Research and development on high quality carbon black in particular and also oil output products for which significant pre-processing and post-processing measures are required.
Economic drivers	All products of the pyrolysis process including char/carbon black, oil, syngas as well as residual steel have potential for use in a variety of applications. Currently, however, overall the economic viability of pyrolysis is low due to the competitiveness of the products in relation to virgin or traditional materials. Overall the added value compared to these materials is low and the cost to produce them is high. Demand will depend on the quality and the competitiveness in relation to traditional or virgin materials. The profitability depends on the added value of the output product. The trend for further development is positive however and tire-derived material (TDM) carbon black is currently in the process of being commercialized by a number of companies mainly based in Europe.
Sustainability considerations	Overall, the sustainability performance of pyrolysis is low due to the larger scale of the less advanced technologies used and unsatisfactory standards of widespread informal operations. Although gas produced by the process can be used to fuel it, where environmental standards are not upheld there can be significant air pollution. This depends on the location however and more advanced forms of the technology are developing with high environmental standards with emissions monitoring.

Reclamation

Criteria categories	Reclamation
Regulatory context	Reclamation is considered as a material recycling technology, and the use of reclaimed rubber in rubber-molded products and/or in new tires is therefore a preferential recovery route according to the waste management hierarchy. The process of reclamation largely relies on the use of chemicals in some areas, as in China or India, and has hence been criticized for the negative environmental externalities it brings about. Governmental action has been initiated in China for instance, to limit the extensive use of chemicals by providing subsidies for cleaner recovery methods.
Technical feasibility	The term "reclamation" covers a number of technologies, with a variety of associated processes and of levels of complexity. This technology has existed since the 1960s, and is well-advanced and at the stage of commercialization. However, reclaimed rubber is usually considered to be a low quality product, and it can be used in a wider variety of products with little added value, such as tubes, liners, cables or tiles. It can also be integrated in the manufacture of new tires although the quality has been considered limited at the current stage of technological development.
Economic drivers	The products of reclamation rely on an important market with a high demand. Indeed, the market for reclaimed rubber was historically strong in some geographical regions, especially in China. However, it is expected to be considerably limited in coming years due to restrictions caused by the environmental impacts of chemical reclamation.
Sustainability considerations	Some traditional reclamation processes, such as chemical reclamation, bring about a wide array of negative environmental externalities, linked to their high use of chemicals. This entails important use of resources, risks of air, water and soil pollution and potential risks to human health. Consequently, these technologies can be negatively perceived by the public.

Steel production

Criteria categories	Steel production
Regulatory context	Steel production from ELT is not supported or constrained in a particular manner by regulatory context. The material recovery aspect will support the recovery route in the context of waste management policy.
Technical feasibility	The technical feasibility is positive for the use of ELT material in steel production thanks to the significant portion of steel in the tire and the capacity for ELT to replace anthracite to provide carbon. ELT therefore can act as reactant, fuel and/or alloy element in the production process. On the other hand, the recovery route is not particularly well developed in terms of current use on a global scale and other sources may be used for the scrap steel portion. In addition, attention must be given to the composition to maintain the quality of the process and product.
Economic drivers	The market for ELT use in steel production is currently relatively marginal in relation to other major recovery routes and there is potential for some slow development. The price of anthracite and other sources of scrap metal, including accessibility of sufficient volumes will affect the economic viability directly.
Sustainability considerations	The ELT material directly replaces anthracite which is a high energy intensive extractive material and also iron ore, consequently reducing upstream energy consumption and emissions.

Concluding remarks

The compliance with or promotion of a waste management hierarchy is a common trend in many of the regulatory frameworks assessed in this study. Energy recovery may generally be constrained by regulatory context aligned with the waste hierarchy. However, other more indirect policies in the context of energy transition such as GHG emission reductions and energy security can be responded to through use of ELT as an alternative fuel with a high calorific value, renewable energy component and reduced carbon intensity relative to fossil fuels such as coal. Some regions or countries have set objectives to encourage recycling and limit recovery, while others have established more stringent regulation to exclude energy recovery from ELT management systems. Setting up grant programs is also common in some areas, such as North America, where subsidies are given for the use of rubber granulate in high value applications, promoting material recycling.

From a technical feasibility standpoint, various recovery routes are capable of treating significant volumes. For instance, cement kilns can absorb large amounts of ELT without significant technical difficulties. However, as a capital investment requirement is required for adaptation, a long-term perspective is required. Civil engineering applications on the other hand do not require the same level of initial investment but have relatively high capacities. Despite the currently limited market, civil engineering may have considerable potential. Meanwhile, TDM obtained through granulation is overall a straightforward well-established process with particularly advantageous properties and performance for applications such as rubberized asphalt.

The economic assessment of ELT recovery routes must make a distinction between those that depend on the added value of output products using ELT as feedstock (material recycling in particular), and those that replace traditional materials or fuel with ELT. The economic models for several granulation applications may require relatively high investment costs for equipment and infrastructure, while the economic viability of other applications will depend on the price of the traditional counterpart (e.g. fuel). The market size must also be considered, as there appears to be room for new technologies, offering innovative products, while the market for certain traditional applications, such as granulate used in artificial turf infill, has decreased.

Although only contributing in part to material recovery, the cement industry, with significant capacity, remains an important destination for ELT provided that a number of economic criteria are met, including traditional fuel costs remaining high in comparison and the availability of gate fees as an additional incentive. For the collection and delivery tied to the cement industry, for instance, this was as simple as the retraction of gate fees provided through extending producer responsibility financial transactions.

Trends have been observed concerning evolving technologies and enhanced enforcement of required standards. Reclaimed rubber operations that are significant in China and on a global scale may be constrained by policies to tackle non-compliance with regard to environmental standards. The related technology devulcanization is now developing under conditions that limit externalities and leave a higher quality output. In a similar manner, informal pyrolysis activities in Asia focused on producing oil are facing a new wave of restrictions, while new safer forms of pyrolysis technology are developing with a focus on other components, notably carbon black and its diverse applications.

The sustainability considerations relative to ELT recovery routes can be assessed through their environmental performance. Some recovery routes have considerable benefits in terms of avoided impacts according to several

LCA studies, such as the use of ELT in cement kilns and in artificial turf infill. Seizing the importance of this issue, new technologies are placing a lot of focus on having environmentally performant processes, with reductions in energy and water consumptions, for example. The impact of these technologies on human health must also be considered, and a wide array of studies have been conducted on those that are considered of potential risk. Nevertheless, public and industry perceptions play a crucial role in the acceptance of these technologies, and therefore in the further development and expansion of recovery routes.

Finally, the major factors differentiating the feasibility of ELT recovery technologies in countries with developing or non-existing ELT management systems when compared with those with mature ELT management systems are directly related to governance and infrastructure. Where little framework exists, the stages of the supply chain lack synergy and consequently, the case for investment in large scale facilities is harder to make.

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