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Review

Implementation of circular economy principles in management of end-of-life tyres in a developing country (Nigeria)

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Abstract: Linear economy principles still dominates production and consumption model across the globe. However, the pursuit and implementation of circular economy model is growing. This model shift is sustained by the global movement towards the concept of sustainable development. Nigeria, a developing country has a very poor waste management system. This paper review discussed challenges and opportunities offered by post-consumer management of end-of-life tyres in Nigeria. End-of-life tyres (ELTs) cause a multi-faceted problem in Nigeria. They are issues with human health (abattoirs, breeding ground for mosquitoes, emissions, etc) and issues with the environment (linear economy, unrecovered resource, air pollution and contaminated land from abattoirs). These two factors form the underlying challenge which the paper addressed. Currently, the management of ELTs in Nigeria has serious negative ecological implications. It takes more than a century for a tyre to biodegrade, occupies much space in dumpsite, is highly flammable, and is generated annually in large volume. The use of tyre in roasting of meat is a common practice in abattoirs across Nigeria. It has led to elevated levels of heavy metals in meat. Therefore, the need for a sustainable approach. Socioeconomic limitations, scarcity of progressive environmental policy, technical and institutional incapacity have severely limited implementation of proper waste management system which is critical for operationalized circular economy. The paper also discussed potential directions on the application of CE model in ELT management, including policy and legislation. Factors unique to Nigeria supports the proposed integration of extended producer responsibility (EPR) and the free market system as the appropriate circular management approach of end-of-life tyres for the country. The study recommends formation of a producer responsibility organization nationally. However, for effective logistics, regionalization of the collection / processing facilities will foster competition and drive innovation in the post-consumer tyre management.

Keywords: end-of-life tyres; circular economy; sustainability; development; carbon footprint; waste management; environmental policy; Nigeria

Abbreviations: ELTs: End-of-life tyres; CE: Circular economy; LE: Linear economy

1 Introduction

Globally, transportation is a very important sector. It drives socioeconomic and technological development. By the year 2050, population of the globe will exceed 9 billion, and number of automobiles will be about 2.4 billion. Population increase, urbanization, standard of living, and demand for mobility have enlarged demand and supply of tyres. There is no proper waste management system in Nigeria. Tons of waste-tyres (end-of-life tyres) are carelessly disposed in the environment [1]. Resources are finite, therefore sustainable production and consumption is the way forward. A major concept that is relevant to sustainability is circular economy (CE). CE is the opposite of linear economy. Linear economy is associated with wastes, and therefore has ecological and economic implications [2]. For example, 13,600 tonnes of sachet water packaging (plastic wastes) are generated annually in Nigeria. The single-use plastic wastes are disposed carelessly, and are associated with flooding in urban cities of Nigeria. It blocks drainage (gutters) systems [3].

Proper management of end-of-life tyres (ELTs) is important to environmental management. Globally, about one billion ELTs are reported every year [4]. ELTs are a viable source of raw materials. A tyre contains rubber, steel and textile [2]. The high heating value of tyres, has led to its use as fuel in roasting of meat in Nigeria. The practice has resulted to elevated level of heavy metals in meat [5]. In Kaduna State, an abattoir uses about ten ELTs daily (3,650 ELTs annually) to roast meat [6]. Burning of tyres releases known human carcinogens such as benzene, 1, 3–butadiene, styrene (suspected carcinogen), toxic contaminants such as dioxosulphate (SO_2), and volatile organic compounds [7]. These pollutants constitute risks to the environment, community health and well-being [1]. The association between poor waste management and greenhouse emissions is a critical issue for developing countries such as Nigeria [8]. It takes more than one hundred years for an ELT to bio-degrade. Therefore, disposing it to landfill is not a cost–effective option. A tyre has 75% void space [5], which stores oxygen. Because of high heating value of rubber, tyres are easily inflammable [1,7]. Waste tyres are habitat for disease-carrying vectors such as mosquitoes and pests [5,9]. Hence, improper disposal of ELTs has negative environmental, aesthetic and health implications. These support the urgency for sustainable and cost–effective approach to manage ELTs in Nigeria. Circular economy offers solutions to the above-mentioned issues.

This work studied the challenges and opportunities offered by implementation of circular management of ELTs in Nigeria. In the first section of the paper, general background, conceptual framework (circular economy), ELTs management approaches and reprocessing are discussed. The second section discussed general overview of tyre market in Nigeria, the challenges and opportunities offered by implementation of CE, based on reviewed literature. In the final section, the paper proposed the way forward towards implementing circular management of ELTs in Nigeria.

2. Circular economy

The concept circular economy (CE) has drawn considerable attention among researchers, institutions and policymakers. It is geared towards innovative and regenerative resource consumption, which is different from the usual linear model [10]. Linear economy (LE) evolved from industrial revolution, as products follows the process of resource extraction–manufacture–distribution–marketing–consumption–repair / re-use-disposal (waste) [8]. Linear economy is shown in Figure 1 below.

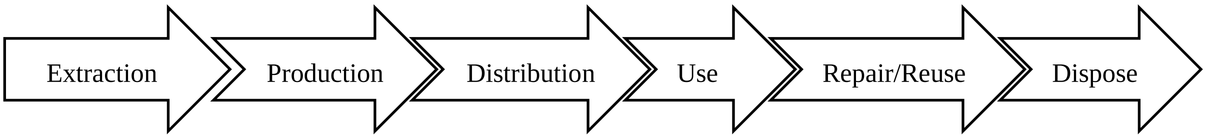

Figure 1. Linear economy.

In linear economy (LE), GDP growth equals more waste going to landfills. Consequently, it is an unsustainable route. The challenge therefore, is to decouple GDP growth from waste generation. This implies close–loop production and consumption cycle [11]. The emphasis of LE is on mitigation measures aimed at ameliorating the adverse impacts of waste generation, for example pollution control. Waste management sector contributes about 3–5% of anthropogenic greenhouse gases (GHG) emissions. It indicates that the sector is important to emissions abatement. Efficient recovery of wastes will reduce emissions in every economic sector [12]. Many developed countries are increasingly decoupling their GDP from waste generation. The opposite is the case in Nigeria, where GDP growth is highly associated with increase in waste generation [12,13]. Total circular economy implies zero-waste. Where zero-waste (total elimination) is impossible, residues that obstruct circularity of materials should be reduced to the barest minimum or avoided totally altogether, in design stage of a product [14].

CE ensures that at the end-of-life of a product, its materials are integrated into circular material flow, for manufacture of same product or another product altogether. Where materials cannot be integrated into material circle, it should be degradable. For example, research to develop a bio-based material (bio-monomers) to substitute petrochemical-based additives in tyres production [2]. CE ensures sustainability, as adverse externalities–environmental degradation and resource depletion is avoided. Realization of scarcity and or limited supply of raw materials have led to strong emphasis on product design. It is geared towards controlling and eliminating wastes at the source. In CE, products are designed for easy separation (disassembly) of its components. Disassembled components can be used for future manufacturing, recycled, and re-manufacture for other uses. Complete transition from linear to circular economy involves re-use, recycling, recovery and prevention in ascending order. Though reuse is the first order in evolution of circular economy, prevention is the important phase. This is because its integration in design, production processes, consumption and recovery ensures circularity of materials and "wastes" [8]. For this reason, CE is referred to as "new regenerative economy," where design is universal and every consumer is a designer. Continuous circularity ensures reduction in extraction of resources, sustainable production and consumption as waste becomes a resource [8,15]. Basic diagram of circular economy and reverse logistics is shown in Figure 2 and 3 below.

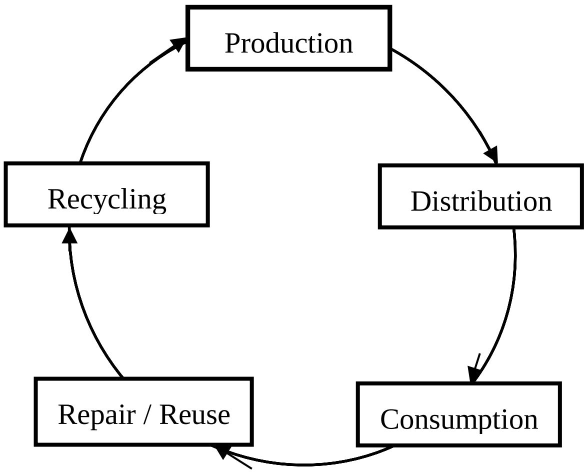

Figure 2. Circular economy.

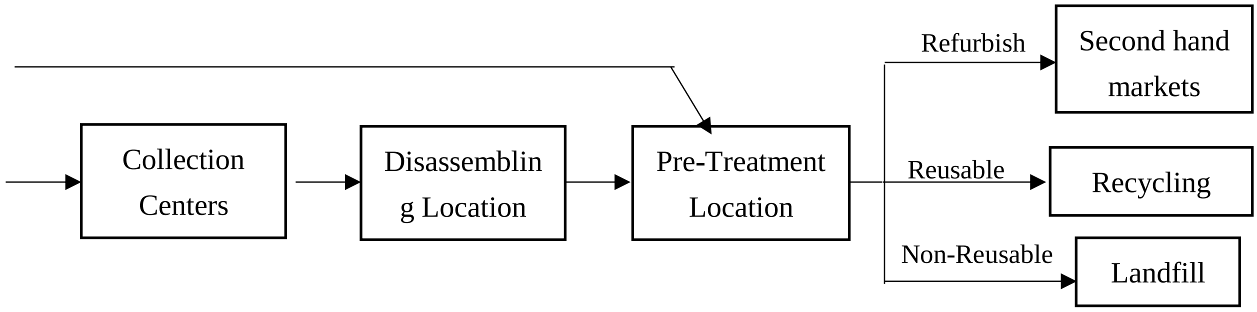

Figure 3. Reverse logistics, after [16].

One item highly used in road transportation that offers great opportunities for CE is end-of-life tyres (ELTs). Tyres are made of composites, irreversible cross-linked matrix rubber, and adhesives. Separating and de-vulcanizing the composites are very challenging, and very difficult. Hence, recycling of tyre is complex. It is therefore common to recycle tyre rubber as a whole in decreasing size as shred and granules. Recovered ELTs are used in production of secondary products. Recycling of tyres provides for steady supply of feedstock-rubbers, steel and textiles, used for production or for other uses [2]. Rubber compounds accounts for about 80% of a tyre's total weight. The others are reinforcing materials (steel) and textiles [17]. Table 1 presents the percentage constituents of passenger, lorry and off-the-road tyre.

CE offers steady supply of resources, for both present and future generation. It is estimated that CE will save US$630 billion in material, for E.U. manufacturing sectors [14]. The U.S., E.U. and U.K. generate 3.3 million, 2.5 million and 480,000 tonnes of ELTs, annually [19,20]. However, in the US, only 10% is recycled into new products, 50% is deployed for energy recovery (tyre-derived fuel oil), and 40% disposed to landfills. In 2014, at the UK, 45% of the recovered ELTs are re-manufactured to other products and materials, 24% (energy recovery) 8.5% retreaded and 22.5% re-used or exported to other market [20]. Recovery and re-manufacturing of ELTs are more advanced in the EU and UK. E.U.'s strict directive on disposal of ELTs to landfills compelled it. The two pieces of legislation which allowed for the improved recovery of tyres in the EU and UK are EC Council directive 1999/31/EC of 26 April 1999 on the landfill of waste [21] and EC directive 2000/53/EC of the European Parliament

2000 on end-of-life vehicles [22]. The legislations outlawed the landfilling of tyres in 2006, and pushed waste managers to recover more ELTs through recycling energy and waste. Accordingly, the importance of adequate legislation and institutional/ infrastructural capacity for reverse logistics and circularity of ELTs cannot be over emphasized. Nigeria needs to tackle these concerns. Circular management of ELTs offers great advantages. For example, the use of rubber asphalt in road construction will benefit Nigeria immensely considering our very poor road network [2]. In 2014, Nigeria accounted for 2% ($5billion) of global tyre market (estimated $250 billion). Hence, substantial recovery of ELTs in Nigeria will provide enormous raw materials for secondary products and energy recovery [17].

Table 1. Average constituents of a tyre.

Constituent	Passenger car tyre (%)	Lorry tyre (%)	Off-the-road (OTR) tyre (%)
Rubber/Elastomers	47	45	47
Carbon Black	21.5	22	22
Metal	16.5	25	12
Textile	5.5	-	10
Zinc Oxide	1	2	2
Sulphur	1	1	1
Additives	7.5	5	6
Total	100%	100%	100%
Total % of carbon-based materials	74%	67%	76%

Source: [18]

Efficient design and implementation of CE requires multi–sectoral participation. The relevant sectors include governments, non-governmental organizations, international organizations, universities, research and development, financial institutions, manufacturing entities, entrepreneurs, consumers and the general public [14]. Various opportunities offered by circularity of ELTs include recycling, re-treading, shredding or rubber crumbing (asphalt for road tarring, floor mats, carpet padding, vehicle bumpers, and adhesives), pyrolysis or energy recovery, and remanufacturing [23].

Generally, there are three management approaches to management of ELTs [24]. They are:

1. Extended producer responsibility
2. Liberal or free market system
3. Tax system

2.1. Extended producer responsibility (EPR)

EPR is an important instrument of CE aimed at holding producers accountable for the environmental effect of their products, from design to post-consumer stage (products lifecycle). Since 2001, various EPR schemes have evolved. EPR purposes easing economic liability of cities and citizens in management of end-of-life (EOL) products; decrease in volume of wastes disposed to landfills, dumpsites; and growth in recycling. Take-back requirements accounts for 75% of EPR scheme. Others are advance disposal fees (ADF) and deposit/refund accounts. Most times, collective EPR schemes managed by Producer Responsibility Organization are established by producers. On the other hand, single producers have established their own systems. EOL streams such as packaging, vehicles, batteries, tyres, electronics, and unused pharmaceuticals are already covered by EPR regulations in Europe [15,25]. Figure 4 presents a basic EPR scheme.

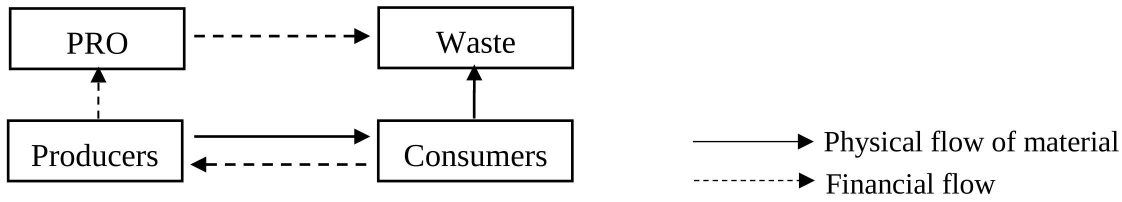

Figure 4. Basic EPR scheme, after [15].

Substantial scarcity of data, methodological challenges in differentiating the impact of EPR schemes from other factors, has limited performance assessment of EPR schemes. Still, EPR has reduced government expenditure on waste management in many Organizations for Economic Cooperation and Development (OECD) countries. It has moved the financial cost from cities and taxpayers, to manufacturers [13]. It is therefore very appropriate to Nigeria, where federal, state and local governments are financially constrained in provision of basic services and infrastructure, including proper waste management [26].

Most often, developing countries do not integrate environmental concerns in pursuit of industrialization and economic development [27]. EPR is therefore a feasible tool to achieve environmental protection and decouple waste from GDP in Nigeria. EPR was introduced widely in Europe in 2001. From 2001–2014, waste streams entering landfill of OECD countries steadily decreased. The observation was related to EPR scheme, material recovery and recycling [28]. By imposing financial liability of waste management on producers, instead of the public, producers are incentivized to prevent waste by adopting eco-design of products. Normally, reverse logistics processes–collection, sorting, transportation, and storage-accounts for 50–80% of EPR costs, while treatment (reprocessing) accounts for 10–40% of the costs [13]. Operationalizing EPR scheme will benefit the whole value chain in Nigeria, thereby creating employment, especially in the informal and semi-formal sector.

To efficiently operationalize EPR scheme in circular management of tyres in Nigeria, the following concerns must be critically addressed:

1. How can producers be mandated to be responsible for their post-consumer tyres (ELTs) [29], since report that 100% of new tyres in Nigeria are imported?
2. Since 80% of tyres (budget tyres) used in Nigeria are mostly imported from Asian countries [25,29], where EPR is not yet a standard practice, who will be responsible for the management of the ELTs?
3. Thirdly, 74% of all vehicles imported into the country are used cars, which suggest that their tyres are probably used or worn out. Also, most of the tyres purchased by Nigerians are decommissioned or ELTs ("tokunbo"), imported/smuggled into the country [30]. How will the producers, even if they have EPR structure manage such third-party transaction?

These questions demand methodological approach, if effective and enforceable EPR is to be designed to manage ELTs in Nigeria. For the first question, how can producers be mandated to be responsible for their brand post-consumer tyres (ELTs), since Nigeria imports 100% of her tyre? The "producer" in this context, refers to the actors placing the manufactured good (tyre) in the country's market. It is not the product manufacturer. Rather, it refers to the distributors and importers of tyres into Nigeria market [15]. It suggests that legislation should be directed to compulsory formation of sectoral Producer Responsible Organization (Tyre PRO) in Nigeria, in order to achieve economic of scale, and cost-efficiency. The PRO should be responsible for collection and recycling of ELT in the country market. Producers may contract out the design and management of the operation to a PRO. The PRO will then be funded by fees paid by the tyre producers. Good example of PRO is eTracks Tire Management Systems, created by Tire and Rubber Association of Canada and European Tyre Rubber Manufacturers Association (ETRMA).

EPR legislation sets annual recovery target, which the PRO or whatever system of the EPR chosen, is expected to achieve each year. Consequently, tyre "producer" has to report total volume of tyre placed in Nigerian market; total volume of ELTs recovered or taken-back (in tons), their suitability for each of the re-processing stages, and operational characteristics for the reprocessing. It means that in Nigeria, where all the new tyres are imported [29], external audit report has to show the volume of tyre imported and numbers recovered. The audit may be carried out according to the total volume of tyre imported and ELTs recovered (for collective PRO), or delineate the sources and brand of import, and their recovery rate. It is expected that some acceptable value (percentages) should be met annually, based on the import of that year. Legislation usually designates the minimum percentage of ELTs to be recovered and the processes (retreading, recycling, remanufacturing, energy recovery) which the collected ELT should be deployed to.

Determining or tracking when a tyre (e.g. new tyre) reaches its end-of-life will be challenging for Nigeria, because of the country's poor management of data. Consequently, it is urgent to determine total volume (by brands) of tyre imported into the country every year. Without this continuously updated or improved data, effective EPR operation will be impossible. To assure compliance, there should be regulation of importation, "producers" (importers/distributors) of tyres in Nigerian market. Presently, there is no legal precedence to anchor or support this scheme in Nigeria. Accordingly, efforts should be directed towards legislation of evidence–based and practical laws, which will operationalize EPR scheme in Nigeria's tyre market. The legislation will strengthen and develop the technological and managerial capacity of the country regarding EPR.

2.2. Tax system

Tax, a fiscal instrument, is used to achieve many objectives-economical, environmental, service provision, etc. It is increasingly being used in pursuit of ecological objectives because of the relationship between socioeconomic activities and environmental pressure. Ecological fiscal policy is a viable tool for financing innovation and efficiency of resource and post-consumer products use. Under ELTs tax system, government is responsible for the collection and reprocessing of the generated ELTs. This is funded by a tax imposed on tyre manufacturers (producers), and trickles down to consumers [24]. In Nigeria, where 100% of new tyres are imported, it may be carried out by levying designated import tariff on tyres, with the aim of recovery and reprocessing of ELTs. The "producers" (in this case, national distributors) pays a tax to the government. The government will be responsible for executing the program and so will finance the operators that recover the ELTs. In the U.S., 26 states finances ELTs stockpiles recovery programs. Also, 37 states require that tyre consumers pay a state tyre fee, at retail shops when purchasing tyres. The state levies are used to fund ELT management program, including staff salaries, research and controlling of accumulated ELTs. The levies vary among the states, and generally, are within the range of \$0.25–\$2.50 per tyre for passenger / truck vehicles. Tyre dealers pay the collected funds into a state government account [31]. Figure 5 shows tax system of ELT management.

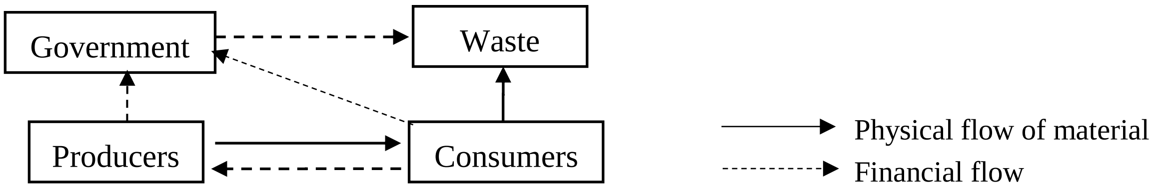

Figure 5. Tax system.

From Figure 5 above, it can be seen that tax system and EPR system have some similar attributes as regards financial flows. Consumers can either pay directly to government a state tyre fee (for example, in 37 states of the U.S.). Alternatively, the producers pay a tax (or fund governments' recovery program). The physical flows of the products for the two systems–EPR and tax system–are the same.

Challenges to effective operation of ELTs tax management system in Nigeria include-corruption, mismanagement, ineffective monitoring and poor compliance to tax policy. Cost–effectiveness determines the success of any ELT management system. Government administered programs, are highly noted for bureaucratic inflexibility, overstaffing and higher administrative cost. Accordingly, administrative cost should be kept to the barest minimum, while greater part of the fund should be committed to actual recovery of the ELTs.

2.3. Free market system

In free market system, enterprise(s) are free to invest in ELTs reclamation and reprocessing. There is no designated national or collective organization (e.g. PRO) responsible for the recovery and re-processing. Enterprises may freely collaborate so as to support best practices. However, legislation sets standards or targets of recovery expected to be achieved [24]. It fosters competitiveness and viability of the management enterprises. Instead of a national organization, firms can tender for viable market opportunities, e.g. in a state or a region. It suggests that the enterprise sustainability depends on viability of its market. The viability depends on size and scope of the market, number of operational automobiles and regularity of generation and recovery of ELTs, awareness and attitude of automobile owners on circularity of ELTs, effectiveness of the system to recover the ELTs, reliability of power supply and transportation system, regulatory framework (taxes, levies, rates), cost–effectiveness of importation, construction, erection and operation of the plants.

Presently, there is poor financial incentives and awareness of circularity of ELTs materials [1,10]. It poses a critical challenge to possible free market operator in Nigeria. However, the opportunities are vast, if these challenges are systematically surmounted. Free market system can be integrated into EPR collective PRO, in collection and treatment of ELTs. Collection centers will have the independence to choose the operator they desire. If free market operators meet the PRO requirements, they can join the system and will be financed by the PRO. The synergy will foster competition and innovation, as PRO is monopolistic.

In most developed countries, vehicle owners take their worn tyres to tyre shop, for replacement. Usually, the tyres are left at the tyre garages. After a certain amount has been accumulated, they are conveyed to recycling or reprocessing sites. Conversely, many Nigerians (40%) continue to use expired or worn tyres [30]. When the ELTs are discarded by private vehicle owners, they are re-purchased for use especially by commercial drivers commuting within metropolis [30]. Also, the ELTs are purchased by abattoirs operators (used in roasting meat), or craftsmen, who burn the tyres to extract the steel. Consequently, the challenge to Nigerian tyre free market operator will be how to induce collection of the ELTs from vehicle owners. Firstly, the legislation banning the use of tyres in abattoirs for roasting of meat should be enacted and enforced. Furthermore, the Federal Road Safety Corps (FRSC) should strengthen enforcement, considering the hazard posed by use of worn tyres. Legislation and enforcement of road safety code, is not enough to motivate collection of ELT for circularity of material and energy. Economics is another factor. Most Nigerians earns less than US$2 a day, therefore monetary incentive should be a factor. It includes deposits, rebates and discounts. Customers should receive a rebate, or discounts, if they purchase new tyre.

2.4. Reprocessing / remanufacturing of ELTs

Circularity of ELTs can be achieved through different processes, depending on available technology, market viability, needs and legislative directives. They are: includes retreading, energy recovery (tyre derived fuel, TDF), crumb and powdered rubber and, material recycling [2].

2.4.1. Retreading

Retreading is the process of reconditioning thread configuration of ELTs. During motion, friction between tyre and road surface leads to worn of the thread. Worn threads are taking out and replaced with a new layer of a rubber material. The tyre must have been designed to be retreaded and must be maintained according to standard method. Generally, low cost (budget) tyre cannot be retreaded, but premium tyres are retreadable [9]. Retreading is exclusively carried out only on truck tyres because of its thicker thread which allows for more successful retreading. Also, its higher natural rubber (NR) content is a very valuable material. Retreading has decreased over the years due to competition with cheaper and more widely available tyres from Asia, which are not always compatible with retreading techniques. Generally, these cheap tyres have reduced the economic return from retreading. Retreading may be pre-moulded (cold-cure treading) or mould-cure (hot-cure) retreading. The number of times an ELT can be retreaded is limited [18]. Some of the benefits of retreading include−70% reduction in new natural resources (steel, oil, and rubber) extraction; 29% reduction in land use for growing hevea; 24% and 21% avoided CO_2 emission and air pollution, respectively; and 19% savings in water consumption. Furthermore, average lifespan of budget tyre is 120,000 km, but that of retreaded tyre is 220,000 km [32]. Accordingly, retreading benefits consumers economically and ensures sustainable use of material.

2.4.2. Crumbing and powdered rubber

The removal of steel and textile constituents and reduction of tyre rubber to granules is referred to as crumbing. Technically, there are two main types of crumb rubber. They are:

i. Whole tyre crumb,

ii. Cryogenic crumb,

In whole tyre crumb, tyre rubber are shredded and fed through a grinding mill. For cryogenic crumb, tyre rubber are cooled below zero temperature (−80 to −120^{o}C) and then reduced to granules.

Crumb rubber is one of the most important post-consumer uses for ELTs, as it serves as feedstock for manufacturing of new products. Recent technological development has made production of crumb rubber from ELTs economically viable and efficient feedstock resources [19].

Chemical composition determines products performance, such as melting point, bonding and physical properties (e.g. durability). Chemical composition of tyres poses a major limitation to the use of crumb rubber. Tyre components are made of different chemicals. Also, each tyre brand (manufacturers) has their specific chemical mix. There is also variation between different parts of a tyre. For example, the tread has much more NR content than the sidewalls or carcass, the inner liner contains more impermeable BR. This makes tyres difficult to recycle due to heterogeneity between components. Therefore, crumb rubber does not have particular chemical properties. This has limited the use of ELTs in remanufacturing a standardized and consistent product. For example, the study of show that only 5% of recycled tyre materials are used in production of new tyres [33]. Recognizing the critical challenges of wide variation in chemical composition of tyres of different manufacturers and heterogeneity between different parts of a tyre, European Committee for Standardization (CEN) has been pushing for industry standards, so as to intensify reliability of its applications [24].

Basically, there are three method of granulation of tyre rubber [34]. They are

i. Ambient granulation;
ii. cryogenic granulation and;
iii. waterjet granulation.

Ambient grinding does not mean grinding at room temperature, as increase in temperature (up to 130^{o}C) occurs during the grinding process. Rather, the rubber tyre is fed into the mill or granulator at room temperature. Ambient grinding involves many stages of processing including removal of steel, separation and grinding. In ambient grinding method, a whole tyre can be processed down to crumb rubber. The tyre rubber is passed through a granulator or mill, in order to achieve decrease of the particle size. The more the rubber passes through the nip zone of the mill or granulator, the more reduction in particle size is achieved. Ambient grinding produces unevenly shaped sheared particles with comparatively large surface area. Therefore, they have improved interaction with composite matrix, and thus higher mechanical strength compared to cryogenically granulates [34].

Cryogenic grinding works on the principle of transforming elastic rubber to a brittle material in the presence of liquid gases (coolants). The conversion of elastic materials to brittle materials is known as embrittle. Cryogens-liquid nitrogen or supercritical carbon dioxide CO_2-are usually used as the coolant. The tyre rubber are cooled below glass transition temperature (−80^{o}C). The liquid coolant also prevents oxidization of the material during crushing grinding by the hammer mill. During the cooling, mechanical action–crushing of the frozen brittle material–through the impact or compression force of a hammer mill is carried out. The production rate of cryogenic grinding is high, and relatively lower energy is consumed. However, pre-granulation and drying process is required for cryogenic grinded rubber. These two process increases the cost of cryogenic grinding. The smooth surface of cryogenic grinded granulated bind poorly with matrix material and therefore the mechanical properties of the composite tends to fail [34,35]. Cryogenic treated crumb rubbers are very appropriate for use in new tyres because of their high value and ease of processing into lesser mesh sizes [31].

A relatively recent and novel method of grinding (milling) tyre rubber, which aims to solve some of the challenges, observed in ambient and cryogenic grinding is ultra-high pressure (UHP) waterjet grinding. It is a method of processing tyre rubber into finer granulates with the support of pressurized water. Waterjets at very high operating pressure (about 55,000 psi) revolve in high speed arrays making clean, wire-free rubbers crumb [36]. In UHP, the whole tyre is used as feedstock, and there is no need for initial shredding. The different parts of a tyre–thread, sides and interior–are treated separately. Therefore, there is segregation of the different rubber compounds that is recovered. The residues (reinforcement) that cannot be processed may be traded as scrap metal. Compared to the other two grinding methods, UHP produces the best rubber crumb–has fine particle size distribution and hence has greater mechanical properties. Composites of waterjet produced crumb (WJC) shows improved tensile and shear strength. The granulates are free of metal and textile materials, has very high surface-volume ratio, there is no oxidation or thermal degradation. Scanning electron microscopy show two sub-categories of water-jet produced crumb (WJC)–particles with complex geometrics and particle with simple geometrics, which is similar to that produced by ambient grinding. Exploiting the ratio of the two sub-categories will further optimize output quality of WJC [33,37,38].

Table 2 below summarizes the advantages and disadvantages of each of the three methods of grinding (or granulation).

Table 2. Advantages and disadvantages of the three grinding methods.

	Ambient Grinding	Cryogenic Grinding	Ultra-High Pressure Waterjet Granulation
Advantages	Developed technology and can process a whole tyre to crumb rubber Relatively cheap to produce Have large surface area Granulates improves mechanical strength of composites	High production rate Low energy consumption There is no oxidation of material (granulate) i.e. high purity. Continuous processing Small particle size produced	Processes a whole tyre to separates different materials Good separation of tyre rubber High surface area–volume ratio of granulates High quality particles There is no oxidation of granulates Improved mechanical properties of composites
Disadvantages	Requires cooling of the system (i.e. high energy consumption) because of heat generation. Poor separation of tyre components (or reinforcements) Poor quality (spongy) crumb	Use and costs of coolants is high It only process rubber that has been coarsely shredded. Granulates have poor physical binding and mechanical properties (smooth particles) Low surface area	The cost of UHP is very high Technological expertise required is high and still novel

Crumb and granulated rubber derived from ELTs can be used in the manufacture of the following moulded rubber products–furniture, signposts, dustbins, wheels, lawnmowers, etc. It may be used in stadium and playgrounds flooring, as synthetic football pitch lawn, roofing materials, courtyards tiles [24]. In the U.S. alone, more than 12,000 school fields, playgrounds and sport centers are covered with pulverized ELTs. Market for ELT granules is already saturated in Europe. Newer markets include rubber concrete, rubberized asphalt, railway and tram tracks, because of rubber's potential to mitigate noise and vibration [39]. Safety concern has increased because of the use of rubber granules in playing fields, etc. For example, while the report that one hundred studies have concluded that it does not pose risk to safety [39], the study of Perkins AN et al. [40] identified 197 chemicals associated with crumb rubber infills which are potential carcinogen. Similarly, Celeiro M et al. [41] identified 24 of 40 target compounds including polycyclic aromatic hydrocarbons (PAHs), cadmium, chromium and lead from samples of synthetic crumb football fields. At best, the paper argues that the link between artificial turf and cancer is inconclusive. This is supported by the reports that "no government agency has concluded artificial turf is safe." [39].

The emerging phenomenon of tyre and road wear particles (TRWP) has been associated with air pollution. The frictional force between the tyre and road surface, during motion and braking, produces abrasion of mostly coarse particles. TRWP contains tread rubber and surrounded road material. It has been connected with particulate matter (PM10, PM2.5) emissions, and is generally high in urban cities with heavy traffic. The characteristics of road pavement have effect on the generation of TRWP. By mass, it is estimated that tire wear contributes about 0.8–8.5% and 1–10% of ambient PM10 and PM2.5. The estimates are established on few studies [42,43].

2.4.3. Energy recovery

Energy recovery is the end of material lifecycle of ELTs. Tyres are a source of fuel. The energy per unit mass of tyre is equivalent to that of oil and slightly higher than coal. It has lower pollution than coal. Therefore, it is a cost-effective source of fuel for industrial processes. A unit passenger car tyre produces 7.6 liters of low sulphur oil. Whole or shredded tyre can be used in energy recovery [24]. Table 3 presents the calorific value (kilojoule per kilogram) of some materials, including that of tyre.

Table 3. Calorific value of some materials.

Source	kJ/kg
Crude Oil	39,500
End-of-Life Tyres	31,400
Anthracite	28,000
Bituminous Coal	26,000
Hellenic (Lignite) Coal	13,000 *
Textiles	28,600
Paper	27,400
Mixed Biomass	25,200
Urban Wastes	5,800

Sources: [27,44]*.

There are three methods of energy recovery from ELTs. They are:

i. combusting with other fuel(s) in operational industrial furnaces (e.g. thermal power station, steel mills, cement kilns);

ii. combustion of only ELTs in specifically-designed incinerators, and

iii. pyrolysis for energy (fuel) recovery.

In Europe, production of cement accounts for the highest use of TDF. TDF is used in rotating fuel-fired kilns. Combustion of tyres in the kiln produces volatile iron oxide, which is a very necessary constituent of cement, reducing the need and costs of clay supply. Anaerobic decomposition of ELTs by heat energy (pyrolysis) produces the following: oil (30%), gas (28%), carbon black (20%), steel (10%) and ash (5%) [44]. Material and energy recovery is achieved by pyrolysis, hence decreasing solid wastes.

Major concern with pyrolysis of ELTs is air pollution (particulate matter, Sulphur dioxide). However, application of emission control technologies addresses the issue [19]. The major concern at its industrial purpose is the cost-benefit analysis of applying emission control technologies, relative to that of using liquid field combustion. Whereas civil engineering use of ELTs is decreasing in the U.S., TDF increased by 48.5%. TDF accounts for 55.5% of ELTs reprocessing in the U.S. [31]. Therefore, TDF is the most competitive of ELTs reprocessing approach.

2.4.4. Material recycling

Material recycling is the most usual management option of ELTs. ELTs are disintegrated into their principal components–rubber, textile and steel. In Europe, the demand for tyre-extracted steel as feedstock for new production of steel is increasing, because of its high quality. Conversely, the use of tyre textile for production feedstock is highly limited. The textiles are usually contaminated with rubber residue. Still, the textile materials are increasingly being used for manufacture of insulation, energy source and experimentally as strengthener in concrete, to increase resistance to fatigue and deformation [9].

2.5. Carbon footprint of new and remanufactured tyre

Apart from continuous circularity of material which reduces virgin resource extraction, another goal of CE is de-carbonization of global economy. Production of new tyres have relatively higher carbon footprint (emissions) than that of reprocessing/retreading. For example, 74%, 67% and 76% of new passenger car, lorry and off-the-road tyres, respectively, are carbon-embodied materials [18]. For retreaded tyre, it is about 50% for each [45]. Accordingly, it suggests that uncontrolled burning of tyres, common in Nigeria contributes to GHG (CO_2) emissions. The study by CRR compared production of new tyres, and retreading. Lifecycle considerations used in the analysis are transport, materials requirement, production energy, and waste generated [45]. Table 4 compares carbon footprint of new and retreaded tyre.

Table 4. Carbon footprint of new and retreaded tyre.

Input	New Tyre (Kg CO_2)	Retreaded Tyre (Kg CO_2)
Materials	48.6	31.1
Transport	9.9	8.3
Energy	31.4	22.5
Waste	−0.1	−0.1
End-of-Life	−2.5	−1.1
Total Carbon Footprint	87.2	60.7

Source: [45]

From the table above, the advantage of remanufacturing is seen. It conserves resources. It is also an important instrument in GHG emissions abatement. Transportation is necessary for both new tyre production and retreading. Raw materials or ELT tyre are transported from production facility and distributed to the market; ELTs are collected from consumers, and back to site for retreading. Transportation equals fuel consumption, CO_2 emission and thus carbon footprint. Transport stages for new tyre contributes 9.9 kg CO_2, while that of retreading is 8.3 kg CO_2 [45]. This suggests that retreading is sustainable (cost–effective, has lesser carbon footprint and emissions). Less fuel is consumed for transportation, compared to production of new tyre. It should be noted that tyre specifications varies, depending on brands.

3. The study area

Nigeria is located in West Africa. The total land area of Nigeria is 910,770 km^2, while water bodies accounts for 13,000 km^2. According to National Population Commission (NPC) census of 2006, the population of Nigeria was 140,431,790. 2019 population of the country is estimated at 199,645,490. Nigeria accounts for 2.6% of global population. It is the 7th most populous country of the world [46]. Thirty-six states and a federal Capital Territory (Abuja) makes up the country. The country is characterized with a very young population. The average age of the population is 17.9 years [47]. Increase in population, economic growth, urbanization and projected growth in standard of living has considerably increased the demand for mobility, and enlarged the country's tyre market. Government ability to provide social amenities/ infrastructure (e.g. proper waste management) crucial to well-being and development will be affected. The country, an emerging economy relies heavily on oil. Oil account for 83% of total export in 2017 [48]. 15% and 70% of GDP and revenue, respectively, accrued from the petroleum industry [49]. Dependence on petroleum export has made the economy susceptible to economic shocks produced by variability in global oil prices, and has limited economic growth. Agriculture is the main source of income for about 33% of Nigerians. The agricultural sector of Nigeria is constrained with many challenges such as deficient agro–technologies, poor irrigation system and land tenure system. Generally, the southern regions of Nigeria are more industrialized and advanced than the northern regions [50]. For example, the three regions in the south have average GDP per capita of $1,880, while for the three regions in the north, it is $1,277. Consequently, 65.3% of household in Northern regions live in poverty, while it is 32.6% for the southern regions [51]. Also, available statistic shows that in 1st and 2nd quarter of 2019, internally generated revenue (IGR) of the three regions in the south is ₦266,067,586,700 ($698.3 million, at exchange rate of $1 = ₦381) while that of the north is ₦113,970,409,549.39 ($299.1 million) [52].CE will innovate Nigeria economy for cleaner, efficient and diversified use of resources. It will increase circularity of materials, reduce waste going to landfills, and create sustainable employment opportunities.

Global demand for rubber is mainly associated with automobiles and other industrial application. Physical and chemical characteristics made the use of natural rubber in tyre production and other engineering products very important [53]. Number of middle class in Nigeria is growing, and purchase of vehicles is projected to increase greatly. It suggests more end-of-life (EOL) vehicles and ELTs will be generated [54]. From 2005 to 2008, 5.7 million units of tyres were sold in the country within the period. Light duty vehicles (LDV) account for 3.9 million units while heavy duty vehicles (HDV) accounts for 1.8 million units. In 2014, a total global tyre sale was estimated at $250 billion, and Nigeria accounted for $5 billion (2%). Growing at 3–5% annually, it is estimated that the country's tyre market will reach $7.5 billion in 2018 [17]. Michelin and Dunlop closed production and moved away from the country in 2005. Consequently, all new tyres purchased in the country are imported. Imported brands accounted for 25% and 90% of Nigeria tyre markets in 2005 and 2008, respectively. In 2005, total tyre production capacity of Nigeria was 2.2 million units, accounting for 75% of Nigeria tyre market. Two classes of tyres exist in Nigerian market namely premium and budget tyres [29]. Budget tyres are relatively cheaper, and are mostly imported from Asian countries [29,55]. It accounts for 80% of total Nigeria tyre market [29].

There are more than 11.7 million vehicles in Nigeria, distributed as follows-commercial (58%), private (40.6%), government (1.19%) and diplomatic vehicles (0.05%) [29,56].At 5.5% GDP growth rate, 6 million new vehicles will be locally manufactured in Nigeria, and the number of vehicles on roads, will exceed 25 million [54].Nigeria is a used-car ("tokunbo") market. In 2014, 74% of all vehicles imported into the country are used cars. 63% are older than 11 years [54]. Accordingly, the tyres' are used, worn and have to be replaced within a short period of time. Most often, used tyres ("tokunbo") are purchased to replace old ones. The practice has resulted to higher rate of accidents and fatalities [30]. Federal Road Safety Corps (FRSC) of Nigeria report that use of worn tyres has led to many accidents and fatalities. For example, 7.4% and 6.8% of auto-crashes in 2013 and 2015 respectively were attributed to worn tyres. 40% of total tyres used in Nigerian vehicles have expired. Use of worn tyres is more pronounced among commercial vehicles [30]. The situation is predicated on the economic situation in the country. World Bank estimate that 83 million Nigerians (40%) live in poverty [57].

Circular economy, which offers waste to wealth path [9], is a sustainable way to tackle health, safety and environment challenges posed by used tyres in Nigeria. It will also offer opportunities for economic and industrial development (job creation and GDP growth). There are great opportunities for its execution, if critical challenges can be surmounted [10,11].

Based on existing practices, our study conceptualized the ELTs management system in Nigeria in Figure 6 below**.**

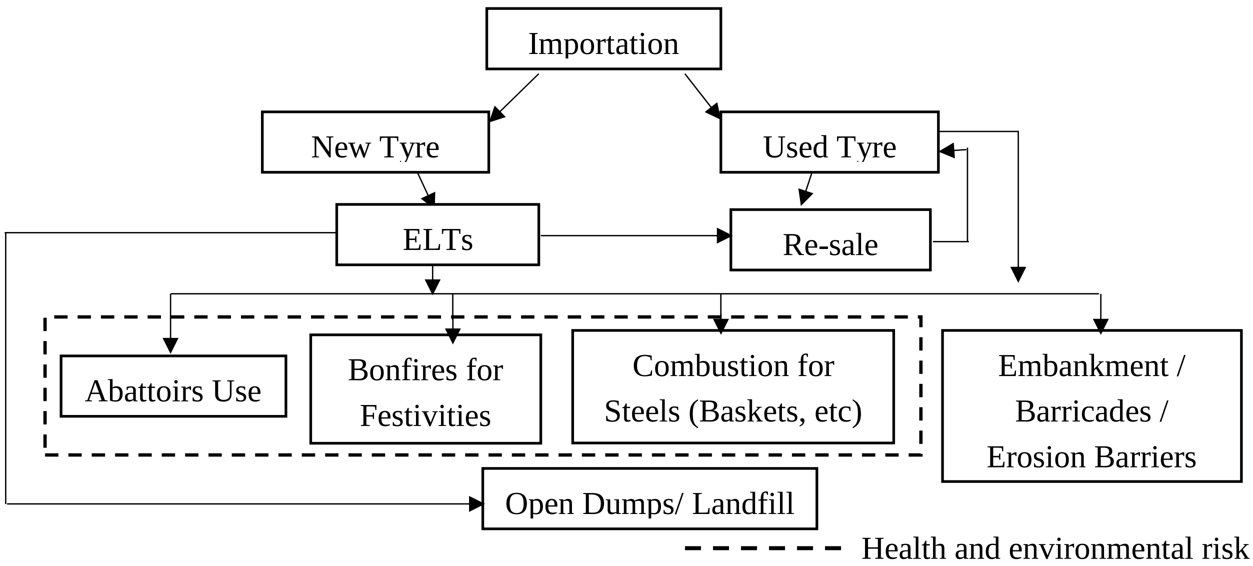

Figure 6. Current management of ELTs in Nigeria.

The current management of ELTs in Nigeria, as shown in the figure above, is unsustainable. The exception is the use in embankment and erosion barriers. The use of ELTs in roasting of meat at abattoirs has resulted to elevated traces of pollutants (heavy metals) in meats [5]. Also, uncontrolled combustion of ELTs produces air pollution, which has adverse health, environmental and aesthetic implications. The extraction of steels (weaving of baskets and other items) from the ELTs is good. However, the open combustion process is not environmentally-friendly. The ashes and by-products are most often dumped in the dumpsites. Therefore, this method of recovery of steel from the ELTs is a very limited (or adverse) recycling process.

Efficient and sustainable recovery of ELTs will assure continuous supply of raw materials, and substantial decrease in ELTs entering the landfill (or dumpsites). For example, within four months' period (October/December, 2006 and April/June 2007), 86.4 tonnes of ELTs were recovered by scavengers from 3 dumpsites in Lagos State. It represents 7.4% of the total materials recovered from the dumpsite [58]. Till recently, developing countries (including Nigeria) have not considered development of CE. Hence, the urgent need to advance legislative framework, laws and regulations which will anchor and scale CE in the country. Developing countries are becoming the major global sites of production, and market. By the year 2025, 1.8 billion new consumers will be added globally. 55.5% of them will be located in developing countries. Transition to CE will result to global sustainable production and consumption [59]. To achieve this, proper waste (ELT tyre) management systems (storage, collection, transportation, resource recovery and recycling and waste treatment) needs to be implemented [60]. Some of the basic requirements and avenues for recovery of waste tyres, exists informally in Nigeria. For example, scavengers recover wastes from dumpsites and streets [58,61,62]. However, circular management of ELTs for Nigeria, requires an interface between consumers (vehicle owners), and third party agents (PRO), on or behalf of the producers. There is therefore need for multi-sectoral cooperation. Consumers, formal waste management sector, relevant government agencies and producers should form a synergy geared towards effective retrieval (collection) of ELTs.

3.1. Challenges to Nigeria adoption of CE principles

3.1.1. Innovation and technological incapacity

Many challenges confront implementation of circular management of ELT in the country. Even in developed countries with state-of-the-art waste management system, only a small proportion of recovered materials are transformed into secondary resources. Globally, about 9.1% of wastes are recycled [59]. Countries that have adopted circular economy and its various forms of instruments have common characteristics–developed economy, strong political will and institutional capacity, cutting-edge technology and efficient service infrastructure [10].

The principles that drives CE are recycling/ re-manufacturing, multi-sectoral cooperation, economic optimization, environmental awareness, transition to renewable energy sources, system thinking, inverse (reverse) approach, waste exclusion, technology driven and innovation[63]. Currently, most of these are seriously lacking in Nigeria. Though recycling is gaining attention in Nigeria, especially in the plastic and paper–based industries, it is still limited in other sectors (including tyre). CE aims to decarbonize global economy. Accordingly, emphasis on the use of renewable energy (solar and hydro). Poor electricity supply is singled out as the most critical factor that led to closure of Michelin and Dunlop production plants in Nigeria in 2005. Per-capita electricity consumption in Nigeria is 136kW, while the regional neighbours, Ghana and Ivory Coast are 309KWh and Ivory Coast 174KWh, respectively [29]. Therefore, poor electricity supply is not unrelated to underdeveloped state of Nigeria economy, and industrialization. Renewable energy and proper waste management is very poor in the country. Absence of suitable waste management principles and the 3Rs (reuse, reduce and recycle), suggest difficult challenges to scale, for CE to be implemented [10].

There is an important association between reverse logistics (RL) and CE. Infrastructural, technological and institutional incapacity have led to poor or absence of RL in the country. Despite these challenges, the opportunities for CE in Nigeria are tremendous because of thriving domestic market (and increasing market potential for automobile tyres). Basis for robust industrial and innovative base that will drive circular management of ELTs is present, since the country accounts for 2% of global tyre market [17].

There exist dissimilarities between Nigeria and South Africa in many key indices. South Africa is leading Africa in pulp and paper recycling [10], recycling of ELTs and other sustainable methodologies [64]. Consequent to Waste Tyre Plan (WTP) legislation of 2012, Recycling and Economic Development Initiative of South Africa (REDISA) was created in 2012. Since then, REDISA has steadily exceeded recycling and recovery targets. In the 3 years between 2014–2017, it has achieved 32.7% recovery and recycling of ELTs. Also, between 2012–2017, ELTs recovery has increased from 4% to 63%, creating 3,000 employments, 200 small scale enterprises, 22 ELTs tyres collection depots and a positive impact on GDP. Approximately 170,000 tonnes of ELT tyres have been recycled, in 2016 [64–66]. The stimulus for the innovation was anchored on WTP legislation of 2012 and technological capacity. South Africa has a diversified economy and viable automobile manufacturing industry, while Nigerian economy is heavily dependent on oil revenue [67]. The reprocessed materials provide feedstock for further manufacturing, hence deepening the scope of CE. Hence, the urgency for diversification of Nigeria economy.

3.1.2. Policy and legislation

Legislation is the main driver of circular management (EPR, tax or free market system) of ELTs [9,13,15,28].Examples include South Africa's Waste Tyre Regulations of 2017 which provided for industry waste tyre management plan (IWTMP) and supported regulatory instruments (EPR) to fund and manage ELTs by producers [66]; Resolution 416/2009 of Brazil's National Environmental Council, which supports collection of ELTs [68]. In Europe, European Union Council Directives 1999/31/EC and 2000/53/EC on landfilling of waste and end-of-life vehicles has given rise to ELTs recovery/ recycling rate of 96%, in 2013 [24,39]. Croatia's Sustainable Waste Management Law (National gazette 73/2017) and Decree on Waste Tyres Management (National Gazette 113/2016) has resulted to about 80% recovery rate of ELTs in 2016 [9]. Japan's Automobile Recycling Law of 2005, has enabled 87% recycling rate of ELTs [4]. Currently, Nigeria has laws concerning solid waste management, which also encompassed ELTs. However, Nukic I et al. [9,39] showed that countries that has achieved important success in recovery and recycling of ELTs have specifically enacted laws to deal with ELTs or its associated waste streams.

Present South Africa's circular management of ELTs occurred because of three advancements–

i. Era of landfilling (starting 1989);

ii. advent of recycling (starting in 2001), which resulted to ban on single-use plastic bags; and;

iii. surge in regulation, starting in 2008 when legislation to curb wastes and resources consumption, was put forward [65].

Since 2012, South Africa has been in the phase of The Drive for Extended Producer Responsibility. It led to Integrated Industry Waste Tyre Management Plan (IIWTMP), managed by Producer Responsibility Organization (PRO) [65]. In Nigeria many waste management laws exist, especially since late 1980s following the illegal waste dumping at Koko (Delta State), and democratic rule in 1999. However, there is no synergy and consistent directional flow of legislation and policy [10]. If Nigeria is to follow South Africa's sustainable transition path, Landfill–Recycling Legislation–EPR, it will be difficult. There is no operational engineered landfill in Nigeria now [60,69]. At best, Nigeria have open or semi–controlled dumps, as informal picking exists, there are no leachate management, few or no controls, etc [26].

Waste disposal to landfills (open dumps in Nigeria) should be a last resort, and not first option. It should be highly reduced through waste minimization or source reduction. The landmark federal legislation on environmental protection (Decree number 58 of 1988), and as amended by constitutional act, are concerned only with reliable systems proper for local, domestic and industrial wastes, monitoring and enforcement of standards for adequate sanitary facilities for disposal of human and other solid wastes, etc [60]. It falls short of legislative stimulus needed to ensure CE (for example, extended producer responsibility of products waste).

With regard to ELTs management, Nigeria can jump the landfilling era (as in South Africa), and enter into cost-effective era of ELT recovery and reprocessing. It will be achieved by modifying advanced CE model existing in other countries to fit Nigeria, considering our existing socioeconomic and technological capability. Waste management policies, legislation and practices in Nigeria is very inadequate and poorly executed. Federal Ministry of Environment is responsible for issuing guidelines regarding major environmental concerns in Nigeria, including waste management. There is a legislation and practice gap, as state governments through state ministries of environments and metropolitan councils are largely responsible for environmental concerns, legislation, execution and administration. Reuse and recycling of wastes is not adequately tackled in Nigerian environmental legislation. Therefore, it can be suitably said that federal and state ministries of environment are majorly concerned with only waste disposal, which most times are not engineered landfill. It has limited Nigerian capability to transform wastes into raw materials [10]. For Nigeria to transition into circular management of post-consumer products (ELTs), legislation need to include integrated waste management techniques and must comprehensively assign roles. Integrated waste management is established on waste management hierarchy: source reduction, recycling, recovery, composting and landfill [26].

4. The way forward

CE is the future of global economy and sustainable development. It assures resource-efficiency and innovation [11]. Though legislative, technological and infrastructural deficiencies presently limit Nigeria executing CE in ELTs market, it should not be deferred any longer. Sustenance of present linear economy (business-as-usual) is not an option. Material consumption is increasing and may exceed earth provisioning and regulating services. CE should therefore be pursued vigorously and urgently. A relevant concern is which of the three approaches of CE management system (EPR, free market and tax system) will stimulate interest, be cost–effective and garner multi-sectoral participation in Nigeria. The chosen system should not be based on its success in other countries. It must take cognizance of prevailing situation in Nigeria-technology, knowledge, infrastructure, practice, legislative support, financial inducement and managerial capacity. Hence, the importance of industrial in-depth analysis.

The in-depth analysis should deal with reverse logistics (RL). RL has existed since the inception of commerce. Since the 1990s, RL has garnered serious attention. CE and RL have similar aim (economic and environmental aspects), actions, and other characteristics. CE model is wider in scope than RL, as it is concerned with both reverse and forward aspects of materials use, and each aspects particular characteristic. RL is a "process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" [70]. Therefore, one factor relevant to RL is collection, and this is very important to sustainability. If "wastes" can be collected back successfully, other processes such as disassembling, recycling, etc can proceed efficiently. Higher rate of collection will translate to higher rate of recycling, remanufacturing, controlling for other variables. Legislation have improved collection rate in developed countries [2,25].

4.1. Infrastructural development and logistics

Policy enabling effective legislation and proper regulatory environment should be the first order, as there is scarcity of both in Nigeria [10]. Stakeholders (multi-sectoral participation) should be involved and will include-tyre producers (importers, distributors), their PRO, retail outlets, tyre users (consumers), governments, NGOs, and the general public. Though effective and updated legislation is necessary, institutions drive efficient regulatory environment. Therefore, our institutions need to be strengthened, so as to carry out monitoring and enforcement duties. The paper advocate integration of free market and Extended Producer Responsibility (EPR) scheme, as the system appropriate for managing ELTs in Nigeria. The ELT management system in Nigeria will therefore require an umbrella organization–a collective PRO. A successful example of such organization is European Tyre Rubber Manufacturers Association (ETRMA). Collective PRO will be more cost-effective than individual PRO, because of economics of scale. In Nigeria setting, the organization should be national, with regional divisions, according to the six (6) geopolitical zones of the country. The free market operators will be integrated, in collection and treatment of the ELTs, while the EPR collective (Tyre PRO) should fund the processes. Such arrangement will drive competition and innovation. Therefore, each area (e.g. state) can chose private operators that will discharge the logistics–collection, transport, etc–based on their proven capacity and efficiency.

It is not sufficient to just recommend circular management of ELT in Nigeria without adequate analysis. There is need for holistic analysis of all the phases (collection, transportation, retreading, energy recovery, remanufacturing, etc), and their operational costs, to ensure viability. Material and energy recovery from ELTs has been shown to be cost-effective in many developed (especially European) countries [2,24]. The economics of ELTs recovery and processes will differ largely between developed countries and Nigeria. The factors to be put into consideration should include amounts of tyre imported into the country, ELTs generated, collection rate, amount that can be processed, power supply and consumption of each processes, equipment/ machineries, process flow, and other dynamic aspects of the operation [44]. Quantifying the actual cost of processing (Naira per tonne or $/tonne) is important in determining suitable price for the circularized products from ELTs. Therefore, the policy and plan towards circular management of ELTs must address four important concerns–location of facilities (collection centers), transportation, renewable energy, and cost–effectiveness of each of the above concerns. Proximity of recycling, remanufacturing enterprise to the collection centers will reduce cost of transportation. The cost of transporting ELTs is dependent on distance between collection and recycling / remanufacturing site, cost of fuel, labour costs (loaders, off loaders, drivers), and other commercial expenses.

The basis for location of the facilities or centers should address the logistic problems of accessibility, availability of electricity supply and market viability. Most Nigerian roads are in a deplorable state. Since sustainable use of resources is the purpose of CE, social, economic and environmental costs should be taking cognizance of. Therefore, the collection and processing centers should be strategically located to reduce transportation costs and minimize emissions (carbon footprint). There is need for a renewable energy supply. Nigeria is endowed with sufficient sunshine almost all the year round, and has great hydroelectricity power potential. Cost–effectiveness (economics) of energy consumption dictates that the marginal cost per unit of recycled/refurbished/re-manufactured products from ELTs be lower than that of new tyres, if productivity should be attained. Energy recovery (TDF) from ELTs is therefore one way for Nigeria to solve the issue of poor electricity supply, drive innovation, create employment, while also achieving resource sustainability.

Differences in economic and technological development between Nigeria (a developing country) and developed countries where advanced recycling processes such as crumbing and pyrolysis is common, implies a different management strategy for Nigeria. The capital investment required to recover and reprocess ELTs may be very costly to Nigerian government, at least by western standards. Also, the capital intensive projects such as incinerators or pyrolysis kilns would be much more demanding to finance and run. This is more acute, as currently there is no operational tyre manufacturing enterprise in Nigeria, which may deploy its available technology for the reprocessing. Therefore, it is important to deploy minimum resources to realize maximum tangible benefits–environmental and economical. Hence, the need for new approach to innovation (or frugal innovation) in reprocessing of ELTs for the country. Frugal innovation (FI) "*is a design innovation process in which the needs and contexts of citizens in the developing world are put first in order to develop appropriate, adaptable, affordable, and accessible services and products for emerging markets"* [71,72]. Therefore, frugal innovation implies providing more tangible (lower resource demanding goods) value at lesser costs. Sharma A et al. [73] showed that FI or resource-constrained product development (RCPD) is critical to achieving sustainability and supply chain benefits., as it reduces material use in production and post-consumer products.

Production indicators such as relatively cheaper labour, lower per capita GDP, fewer or non-existent state-of-the-art facilities and capital dictates the need for frugality in reprocessing of ELTs in Nigeria. For example, some products which may be made from ELTs in Nigeria, but not in advanced countries, include weaved basket and binding iron used in buildings. However, the processing should be carried out in an environmental-friendly manner (i.e. combustion of the tyre). Extraction of steel from tyre will offer a growing supply for demand of binding wire (used in building) and weaving of basket. These do not indicate that advanced reprocessing of ELTs in Nigeria should not be pursued. Crumb rubber may be an important tool in governments' effort towards improving road network in the country. Also, energy recovery can play a critical role, especially for industries that already have the technology (especially cement plants). Development of technical and investment partnership from established foreign enterprises should be pursued so as to scale-up advanced recovering / reprocessing of ELTs. The use of rubber tyre in road asphalt and energy recovery is very relevant to Nigeria developmental needs.

4.2. Management structure

The paper advocate regionalization of the treatment centers. Currently, there are six geo-political regions in Nigeria (South East, South South, South West, North Central, North East and North West), comprising the 36 states of the federation. Every state in each of the regions should have their own collection centers, from which it is scaled up and transported to the regional collection centre. It means that there should be a central state collection centers. ELTs from different collection points in the state will be transported to the state's regional collection centers. Economics of scale is a major factor in competitiveness of bulk transportation of materials (including ELTs) [8,45,64]. The regionalization will foster competitiveness and cooperation, thereby developing the scope and depth of recovery and remanufacturing of ELT tyres in Nigeria. Figure 7 below shows our proposed circular management of ELTs for Nigeria.

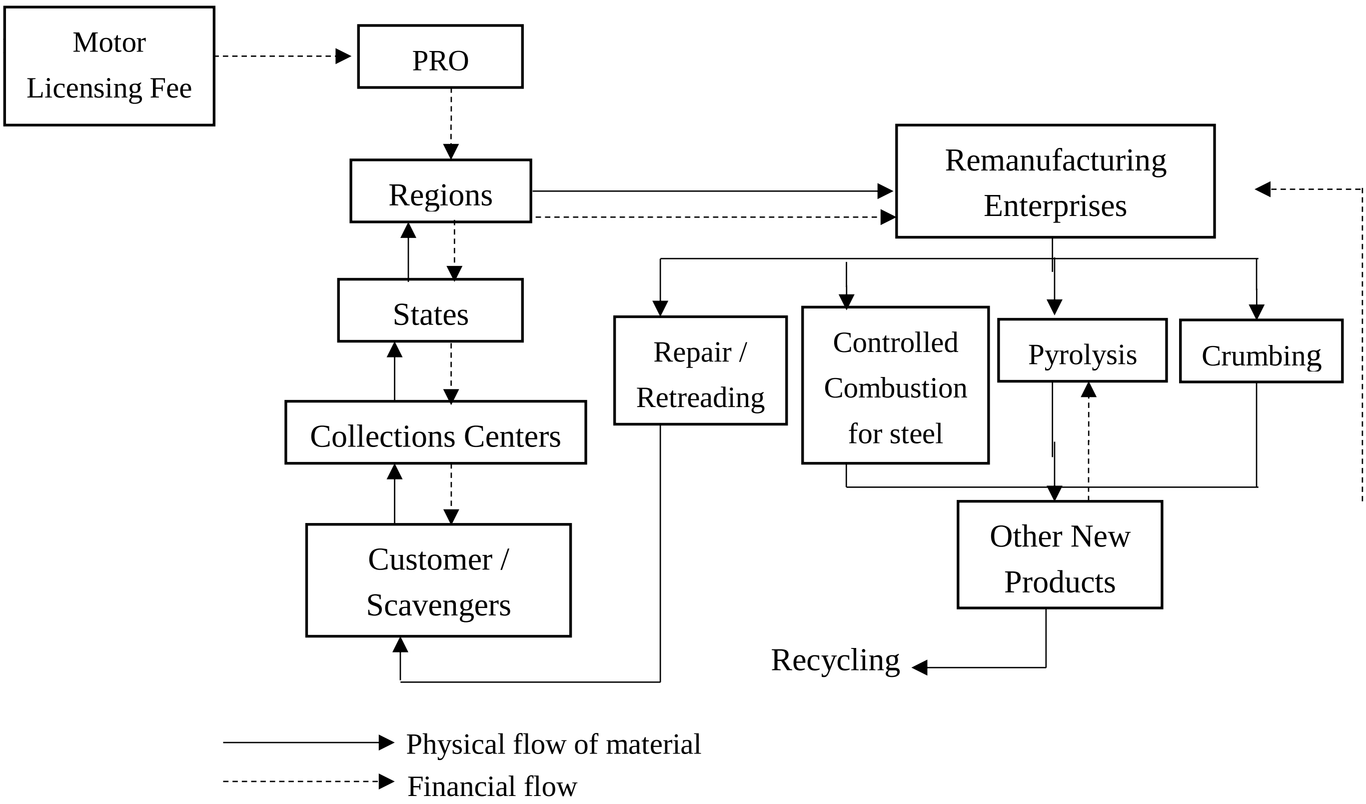

Figure 7. Proposed management of ELTs for Nigeria.

After the fixed cost of plant, transportation has the second highest cost in RL [74]. Presently, Nigeria does not manufacture, retread or recycle tyres [29]. Recovery of ELTs across Nigeria with the sole aim of shipping it abroad (for reprocessing) will greatly add to the cost of logistic thereby limiting cost-effectiveness of the management. Accordingly, econometric model should assess the demand and supply (viability) of circular management of ELTs in Nigeria market.

Nigeria's economy is largely a free market system. Individuals have the right to own and operate their businesses. Yet, government influence on job creation, market directives, and economic sector is pervasive. The effect of over-dependence on revenues from petroleum proceeds has largely centralized the economy. State governments receive monthly allocation from the federal government. The centralization of the economy has highly limited industrialization, innovation and hence development. Bureaucracy and incompetence has severely affected government efforts to operate industrial enterprises [66]. Conversely, private sector is dynamic, have managerial competence, can generate and access funding, improves on knowledge of technologies, innovates and takes risk, and is not constrained by bureaucratic bottleneck [11]. Therefore, responsibility for the logistics of the ELT management should be solely handled by private operators (third parties) contracted by the PROs, in every State of Nigeria. A regulatory entity should regulate the operation of the private sectors, in compliance to pertinent regulation, which will be put forward. The regulation should include the whole aspects of the operation.

As earlier discussed, Nigeria imports 100% of new and most of the used tyres, used in the country. They are often imported through land borders, or accompanies freight of used cars (and other used goods) shipped from across the continent. Most often they are unaccounted for and unquantified [29,54].

To tackle the ELTs generated outside the normal channel of the producers, which is beyond the jurisdiction of the producers (and their PROs), government should

i. enact legislation making disposal of tyres to open dumpsites (or landfills) a punishable offense,

ii. set up a system where those that returns their ELTs are given credit towards purchase of new tyres, and;

iii. the given credit should be based on value assessment of the state of the ELTs, so as to ensure competitiveness of the enterprise.

To avoid duplicity and higher overhead costs for services and administration of the ELTs management scheme, points (i)–(iii) above should be designed and integrated into the PROs management scheme. Since data on total volume of tyres imported by individual producers (and/ or collective PRO) per year into the country will be available, and this will determine the proportion of fund to be paid by each producer. The extraneous ELTs financial burden may be paid for by slightly increasing the annual motor vehicle registration levy. Specified percentage of the levy should be channeled to the ELTs management scheme of the PROs. It is not an equitable (or perfect) solution, as drivers that uses new tyres purchased from any of the producers registered with the collective PRO, are also made to bear the financial burden of managing ELTs unregistered with the PROs.

The arrangement should be modified as the scheme advances in Nigeria. Proper accounting and levying of appropriate rates on imported used tyres are important. The fund should be remitted to the PROs fund to enable reprocessing of every ELT in Nigeria. Econometric model is therefore required. The model should take the following into account–annual tonnage of imported used tyres, recovery rate of the tyres, depreciation rate and unit cost of reprocessed materials.

Historical stockpiles of ELTs in dumping/storage facilities are another concern. Recognizing Nigeria's infrastructural, economic and waste management system, energy recovery (pyrolysis) seems to be the best way to recover this material. They may be combusted with other fuel(s) in operational industrial furnaces (e.g. thermal power station, steel mills, cement kilns). Outside of the suggested formal ELT management structure, industrial outfits that uses furnaces, should be motivated (financial incentives) to use/combine this energy source. However, the enterprises should pay for the logistics of transporting the ELTs to their facility.

5. Conclusion

ELTs cause multi-faceted problems in Nigeria: issues with human health (abattoirs, breeding ground for mosquitoes, air emissions, etc) and issues with the environment (linear economy, unrecovered resource, air pollution and contaminated land from abattoirs). These two factors form the underlying challenge which the paper addressed. The current method of managing of ELTs in Nigeria is not a sustainable means. Circular management of post-consumer product is important to sustainability. There is scarcity of legislation pertinent to proper waste management of ELTs, which is critical to implementation of its circularity in Nigeria. Legislation is principal to innovation and achievement of circular management of ELTs. The major approaches to management of ELTs are EPR, tax and free market system. Retreading, crumbing and energy recovery (pyrolysis) are major methods of reprocessing ELTs. Factors unique to Nigeria, implies that what is obtainable (state-of-the-art technology and processes, economic indicators) may not be feasible in Nigeria, for now. Therefore, it is necessary to develop a local alternative to management and sustainable use of ELTs. For example, use of steels in basket weaving, binding wire used in construction and other feasible local alternatives. Our paper advocate innovative legislation empowering recovery and reprocessing of ELTs, integration of free market and EPR scheme as the suitable option. The management structure should follow the present geopolitical structure of Nigeria, with each region having a reprocessing center. Private service companies registered in each state should collect and transport the collected ELTs to the regional treatment facility. The receipt of the services provided by the companies should be paid by the PRO, and should be dependent on the tonnage (amount) of ELTs recovered. The PRO should comprise of importers/ distributors of different tyre brands in the country. The amount paid by each of the tyre brands (producers) should be a percentage of their annual importation into the country. An oversight (or administrative) body comprising of representatives of inter-agencies–Federal Inland Revenue, Nigeria Customs, Ministry of Industry, Manufacturers Association of Nigeria, and tyres Producer Responsibility Organization (PRO) should be formed. The body should ensure compliance of the private service companies contracted by the PROs to run the program in each of the state. There is therefore need for comprehensive collation of data, by Nigerian Customs Services and other agencies related to importation of different tyre brands into Nigeria. This will inform the amount of fund to be deposited by each tyre producer into the common EPR fund. Implementation of circular management of ELTs will allow for increased sustainability in the Nigerian waste sector.

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Conflict of interest

All authors declare no conflicts of interest.

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