Sustainable End-of-Life Tyre (EOLT) Management for Developing Countries – A Review

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Abstract

End-of-life tyres (EOLT) a problematic source of waste belongs to a type of solid waste named "bulky" in waste management. It constitutes a lot of environmental issues which ranges from causative of fires hazards to health and hygiene menace. A holistic waste management technique will go a long way to determine a proper handling, re-usage, reduction, recycling and disposal of EOLT and peradventures make EOLT a huge waste to wealth venture. This article reviews the management, re-use and recycling of EOLT in developed countries as compared to that of developing countries. Some pertinent gaps in the national managerial policies and programme governing the collection, storage and recycling of EOLTs were identified. The article conclusively proffers a managerial pathway that will optimize the opportunities of Waste to Wealth resources in EOLTs in developing countries thereby contributing to their economic advancement.

Keywords
End-of-Life Tyre, Waste Management, Recycling, Policies

1.0 INTRODUCTION

End-of-life tyres (EOLT) refers to tyres that have exceeded their useful lifespan due to deterioration of certain properties that make them road worthy. EOLT are usually available in sufficient number to stand as a hazard to environment and society as well as be 100% advantageous if well utilized and managed. In the early 1990's, developed regions such as Europe and USA started taking steps to strengthen their engagements in the management of EOLT to take advantage of available resources through exploitation for various uses ranging from energy generation, civil constructions, material recovery and other innovative uses. Stockpiling of EOLT was set to be greatly reduced to 0% resulting into reduction of problems of fire outbreaks from those dumps, breeding vectors in certain climates in these regions. Generally, in developing countries effective Waste management has been limited by problems like poor infrastructure, insufficient funding, attitudinal behavior of the citizen, graft on the part of public officials, dysfunctional legal and majorly poor policy framework (Omole, Isiorho, & Ndambuki, 2016). Like exploration of natural resources, many underdeveloped and developing countries especially African countries are still on a slow lane in advancing the EOLT management and harnessing of the resources therein EOLT. Most developing country's government policies have not been able to address this available socio-economic benefit. It is obvious that regulations and infrastructure for EOLT management can be greatly improved in developing countries (Godfrey & Oelofse, 2017).

In this paper, Section 2 described EOLT in details while Section 3 highlighted the composition and properties of different forms and stages of EOLT recycling. Section 4 identified the current uses of EOLT and reviewed different classes of useful materials that can be extracted from EOLTs. Section 5 Identified some established techniques from developed countries. Section 6 suggested direction towards better exploitation of EOLT resources in low income and middle lower economies succinctly describing some managerial pathways that will strengthen the opportunities of Waste to Wealth resources in EOLTs in developing countries thereby advancing their economies.

2.0 END-OF-LIFE TYRES (EOLT)

End-of-life tyres (EOLT) refers to tyres that have exceeded their useful lifespan in terms of roadworthiness i.e. tyres that had burst or have been utterly damaged beyond a safety limit for usage in vehicles for transport due to deterioration of certain properties like eccentricity, flat and balanced surface, grip surface among others. At tyre birth, their material is a constituent combination of synthetic and natural rubber, to which are added a range of specific substances to ensure performance, durability and safety. These include mineral oil, reinforcing fillers (carbon black and silica) and vulcanizing agents (Sulphur) which act as catalysts to accelerate the vulcanization process. (Karagiannidis & Kasampalis, 2009). With proper tyre maintenance, a tyre is expected to last on the average for more than eight years. However, due to some factors like relatively hash working condition and intensity of use, tyres develop to begin to display a significant ageing damage after about 6 years thereabouts. Because of concerns over tyre ageing, which results in reduced tyre performance and safety, many consumers would replace their tyres at about 5 to 6 years of usage even before their treads were fully worn out (Weissman, Sackman, Gillen, & Carl Monismith, 2003).

Waste tyres fall under the category of solid waste. Its existence as solid waste gives rise to landfilling, health and environmental challenges. A majority of these waste tyres accumulate in landfill sites or are being illegally disposed of in open land fields (Viglasky, Viglasky, Klukan, & Jezo, 2017). These problems are domicile in regions where there exists no form of management policy to control the exploitation, disposal and possible recycling of EOLT. Developed countries that have clearly defined waste management and energy maximization goal have put some policies in place to check the usage and disposal of EOLT, first to avoid wastage and hazardous disposal and second to maximize the resources borne in EOLT (Phale, 2005). These policies are discussed in this article and then the reviewed in comparison to the situation of developing countries.

3.0 MATERIAL COMPOSITION OF EOLT

Below is a charted description of proximate material constituents of EOLT.

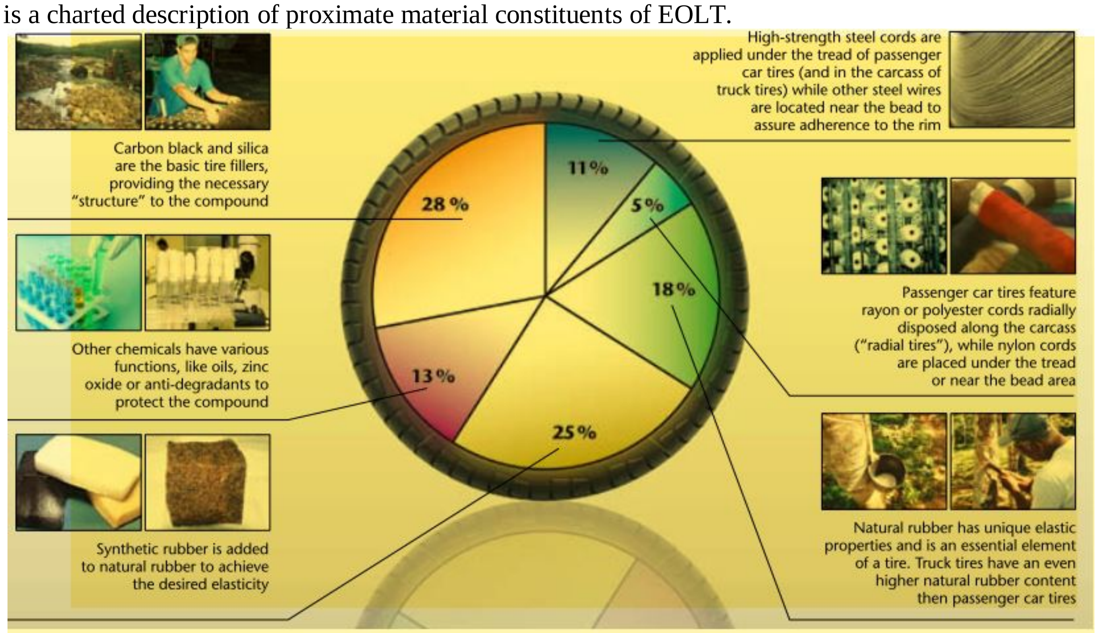


Figure 1: Composition chart of a typical EOLT (*Managing End-of-Life Tires*, 2015)

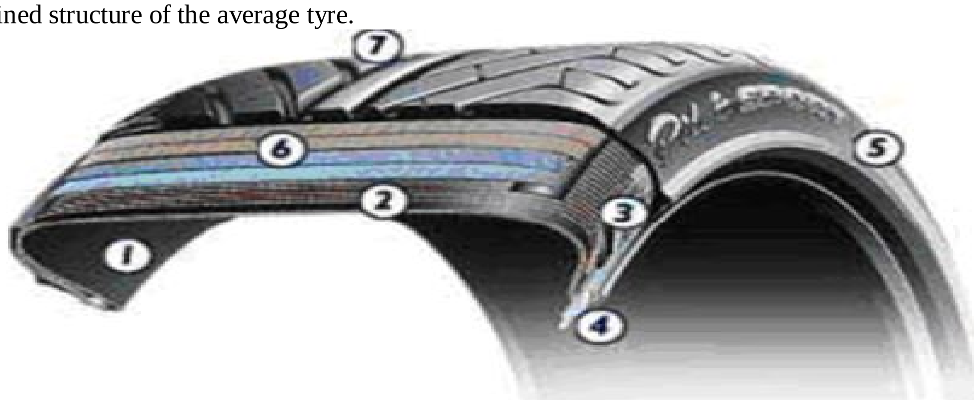
- Carbon black occupying the most portion of the material constituents, about 25 per cent has its usefulness in providing compound structure.
- Synthetic rubber about 25 per cent is also abundant and guarantees elasticity in tyres. It is usually combined with natural rubber to achieve this.

- Natural rubber, an essential component exists in tyres to cater to unique elastic properties. They are often combined with synthetic rubber for better elastic properties
- Steel cords are also a major component of the tyre. They help to align the rubber portion of the tyre to the rim. I.e. for structural support.
- Other constituents existing in minor amounts include oils, zinc oxide or anti degradants for protection purposes. Rayon, polyester and nylon cords also exist in minute portions (Juan, 2013).

Considering rubber and carbon as the major components by mass, four types of rubber exist in the form

- Natural rubber
- Styrene-butadiene rubber (SBR)
- Polybutadiene rubber (BR)
- Butyl rubber (with halogenated butyl rubber).

First, three rubber types are essential for thread production but butyl rubber is used within the tyre. Below is a rubber defined structure of the average tyre.



1-inner layer (butyl rubber), 2-frame fibre (fabric), 3-steel cord belt layer (steel), 4-circle core (steel wire covered with rubber), 5-side edges (natural rubber), 6-bandage (nylon covered with rubber), 7-protector (synthetic and natural rubber)

Figure 2: Structural features of a typical rubber tyre (Rochas, 2010)

Considering carbon to have high mass percentage content. Presence of carbon makes tyres very useful even at their life ending because of the vast industrial application of carbon in the energy industry as it has high calorific value as well as in material industry in the form of carbon black. Carbon black is used for pigment, rubber strengthening and UV. Protection (Viglasky et al., 2017).

4.0 SOME IDENTIFIED PRESENT USAGE OF EOLT

Forms that EOLT can be transformed to before recycled usage include:

- *Whole tyre form* – This form utilizes the tyres as they are after the rims are taken away. No further shredding or processing is required. This form usually found useful in sound barriers, road embankments, erosion barriers, coastal protection, artificial reefs, avalanche shelters, slope stabilisation, breakwaters, insulation and landfill construction operations. Their usage extends to the farming sector as silage clamps though on a very small scale (Campbell, 2008).
- *Shredded tyre form* – whole tyres can be shredded by subjecting them to certain mechanical technologies. Shred sizes could range from 25-300mm depending application requirements. Tyre granule aggregate is useful for walkways, roads, railways, landfill construction. Tyre derived aggregate has been found to be 30-50% lighter than sand and gravels thus useful as sub grad fill and embankments also as backfill for walls and bridges. It drains 10 times better than well-graded soil and provides 8 times better insulation than gravel thus useful as a draining material replacement for sand and gravels (Hu, Cheng, Wen, Chen, & Hu, 2014).
- *Crumb and powdered form* – this entails reducing tyres to rubber to granular form after the steel and fabric components are taken out. Application of powdered tyre extends to moulded rubber products and flooring for playgrounds and stadiums taking advantage of the absorbing characteristics and elasticity of the rubber

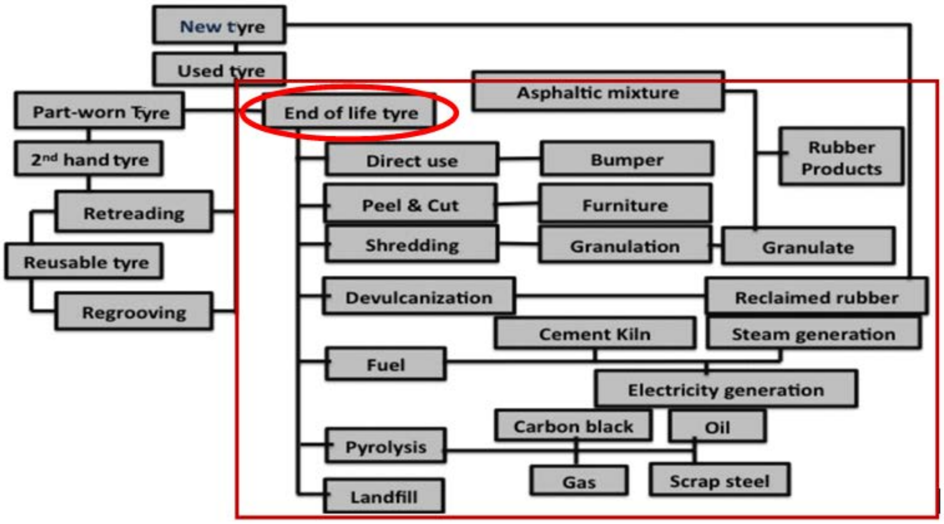


Figure 3: Tyre Life Cycle showing recycling options and potential products (Connor et al., 2013).

The figure above is a designed managerial Flow of groups of EOLT to various End products ranging from Engineering products to tyre oil which can serve as an alternative source of energy. At recycling, some by-products and end products at some stages will serve as raw materials to other industries thereby reducing the waste at the end of the recycling programme. At the last stage; a safe and efficient means of disposal had been attained. Considering the usage related to recycled EOLT products depicted in the above figure, two major markets can be identified as Energy and Material products (Muzenda, 2014).

4.1 Energy recovery

Tyre-derived fuel (TDF), an indisputable disposal option for EOLT, has been reported to be widely used in thermal power stations, cement kilns, steel mills, pulp and paper mills and industrial boilers as an energy source. Tyres reportedly have a high energy content and match up sources of energy compared to other solid fuels. In Europe, cement industries are major beneficiaries of fuel or energy from EOLT. Kilns are increasingly being equipped to use EOLTs as supplementary fuel and still be in compliance with the 2008 atmospheric emission standards (Pehlken & Essadiqi, 2005). The net calorific value of tyres is within 26 and 34 Giga $joule/tonne^{10}$ similar to that of coal and some other common fuels. A tyre burns completely at 650°C, producing carbon dioxide and water, with some inert residues such as slag and ash. The temperature inside cement kilns, at 1800°C, is significantly higher than this thus ensuring complete combustion. Cement kilns will accept whole tyres as fuels though for larger scale cement bays since it saves preparation (quartering or shredding) costs (Ogilvie, Macdonald, & Karlik-neale, n.d.).

Presently, energy recovery takes forms such as Co-combustion in existing industrial furnaces such as cement kiln as mentioned above, combustion in dedicated incinerators and then pyrolysis for material recovery. Reports have it that as a comparison, coal provides up to 29 MJ/kg while tyre rubber provides about 32.5 MJ/kg of energy, hence a more profitable energy option (Jansen, Schmeitz, & Maas, 2014)

Using TDF has many advantages including:

i. Reduced emissions- considering the fact that EOLT is burned in a controlled environment of the kiln. Coal and other solid fuels have a higher carbon content per unit fuel while that of EOLT is relatively lower and hence reduced greenhouse emissions.
ii. Lower costs- cost of using EOLT is lower than using fossil fuels such as coal, oil etc. Apart from the fact that those kilns are big enough to accommodate a whole big tyre without any operation to reduce the size, Shredding is not a costly operation and hence it’s lower cost in comparison both ways.

Having mentioned all above insights about TDF, the possibility of having this class of EOLT usage as a major focus in a developing country might not be very advisable because having industries related to cement kilns, thermal power stations, steel mills and industrial boilers evenly located around a developing country may not be so much expected. That invariably shifts our attention to the alternative material market of EOLT as the optimum option to be looked into (Juan, 2013).

4.2 Material recovery

Solid products in this class of EOLT recoverable includes steel, rubber in its natural and synthetic form, carbon black or graphite, rubber granulates among others. The material composition of tyres made it possible to recover a wide range of many useful materials retrievable by either mechanical, chemical or thermochemical processes (Athanassiades, 2013). Material recovery can be divided into recovery for civil engineering uses and for general engineering uses.

i. *Civil engineering wise,* whole or shredded wires can be used for the various application. These include road insulation, backfill for walls, embankments, field drains, rainwater runoff barriers/erosion control, marsh and wetlands establishment, crash barriers, speed humps and jetty bumpers. Are positive options for such uses due to characteristics such as lightweight, good permeability, shock and noise absorbing, durability etc (Poulikakos et al., 2017).

ii. *General engineering application wise,* rubber modified asphalt can be gotten from the grounded rubber. This asphalt can be used for pavements. Asphalts embedded rubber have advantages such as longer lifespan and less noise A lots of researches are ongoing on the recycled rubber blend with polymers and also to increase rubber use in asphalt in varied climates. Rubber granules are produced either by cryogenic (freeze) grinding or ambient grinding, the former is obtained by using liquid nitrogen to freeze the tyres before file processing producing finer particles (Hu et al., 2014). Material recovery also finds usefulness in steel extraction for steel rims or rods, road surfacing, flooring and mats or adhesives (Ogilvie et al., n.d.).

Table 1: Summarized Trends of Material recovery from EOLT at different tyre sizes.

Technologies/Applications	Examples	EOLT Form/Sizes
Civil Engineering Applications	Erosion barriers, Sound barriers, Avalanche shelters, Road embankments, Landfill construction operations Slope Stabilization.	Whole
Civil Engineering applications	Draining materials, Backfill for walls, Subgrade insulations.	Shredded
General engineering applications	Using as wheels, Rubber modified asphalt, Floor for playgrounds and sport stadiums Artificial turf for football fields.	Powdered

(Muzenda, 2014)

Below is a graph that depicts the evolution of tyre recovery industry till 2013.

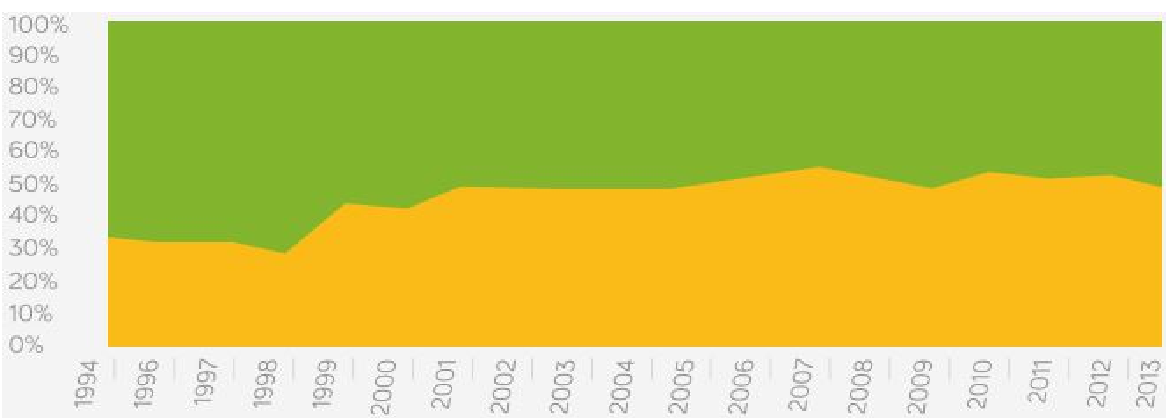


Figure 3: EOLT recovery evolution Source:(ETRMA, 2015)

5.0 EXISTING MANAGEMENT SYSTEMS FOR EOLT

Maximizing resources from EOLT by preventing misuse, wastage and negative exploitation is a step towards harnessing EOLT's potentials. In Europe, recovery or collection of EOLT generally follow three (3) major systems namely: Producer responsibility, Government responsibility and Free market system.

5.1 Producer Responsibility (PR)

This system is otherwise known as "tyre industry responsibility". This system operates that tyre industries have virtually absolute responsibility for recovery, recycling and disposal of EOLT's. Financing of the management process is done in accordance with the number of tyres produced in a country and finances allocated per unit production. Tyre manufacturers collaborate with distributors and retailers under what is called a "stewardship system". Stewardship is an ethic that embodies the responsible planning and management of resources. In some countries, tyre manufacturers are made to promote EOLTs as a resource under producer-responsibility systems. Most countries in Europe now have these systems, accounting for over 50% of European EOLT volume (Dierick, 1994). Often referred to as *extended* producer responsibility, this clause actuates the producer's full or partial operational and/or financial responsibility for a product extended to the post-consumer state of a product's lifecycle. The post-consumer state is the state considered here and the producers have put their products under the law to return as a property right after the life cycle has been reached. Invariably, under this system, the manufacturer has a duty to ensure that the waste from the products it created is collected and disposed of responsibly. In other words, the producer is responsible for the waste generated by the consumers. (ETRMA, 2015).

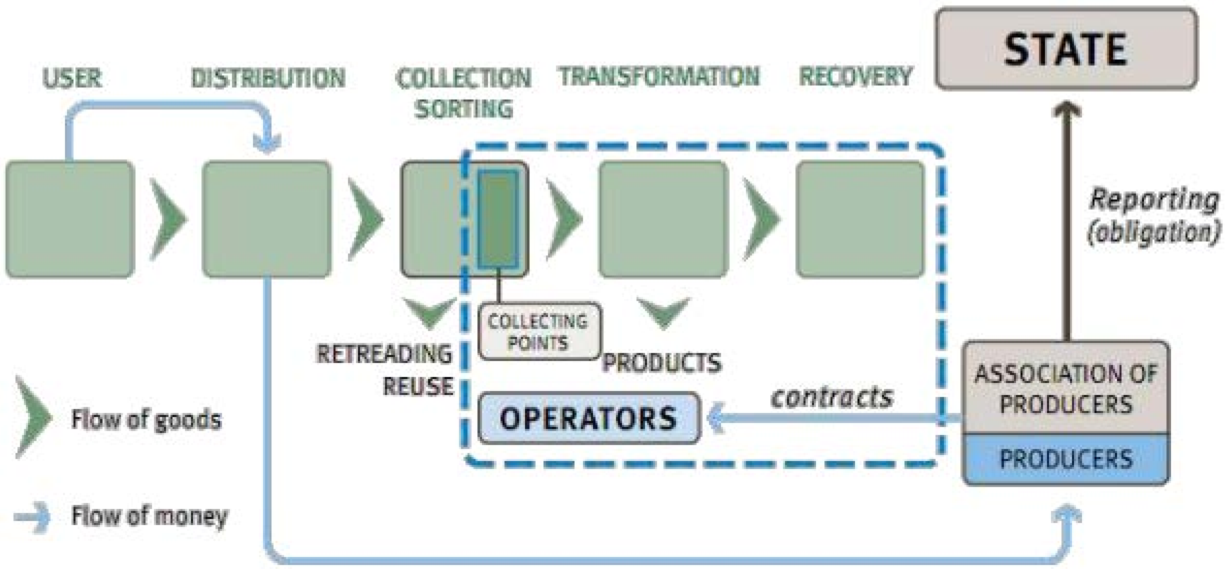


Figure 4: Flowchart of Producer Responsibility (Jain, 2016)

In cases of EOLT management companies having affiliations with tyre manufacturing companies, financing is done by a tax rate or fee placed by EOLT management companies on tyre manufacturers or tyre importers. These fees are passed down through a value chain down to distributors and even to end users. Thus, financing exists in form of an environmental contribution as it is spread across of levels of markets even till the end market. Producer responsibility is about the most used in European regions with about 21 countries adopting a legal framework that assigns the responsibility of the post-life management of tyres to the producers. 28 European countries, Turkey and Norway inclusive, inculcate this management system (Mulenga, 2015). Stewardship systems as explained above exist in countries such as Brazil and Korea. In Brazil, importers are bound by a stewardship agreement to bring to disposal 20 per cent more tyres than they import yearly while in Korea manufacturers and importers pay a deposit fee that is bound to be refunded when they collect the EOLTs. Turkey and Russia are on a beginner level in Producer responsibility and stewardship system.

5.2 Government Responsibility

Since this management system employs taxation practice, it is in some texts referred to as the "national tax system". It is more or less a community responsibility to finance the recycling of tyres proportional to usage. That is, under the tax system, each country is responsible for the management of EOLTs. It is financed by a tax levied on tyre producers by government policy and subsequently passed on to the consumer. The implication is that tax levied on tyre sales are used to run the EOLT management system. On the end of the government, they can take the direct role of cleanup establishing government agencies under their environmental ministry to take charge of cleanup of tyre dumps around a country. Considering Canada, bodies administered by government are established in about half their provinces thought not covered by stewardship systems (Godfrey & Oelofse, 2017). Canada alongside involves industry and other stakeholders in the management of EOLT's. Countries such as Croatia, Denmark, Latvia, Slovak republic follow this national tax system.

5.3 Liberal system (free market)

This system gives various EOLT management firms a free market to invest in recovery and recycling of tyres. However, the government or legislation sets the objectives or standards of recovery to be met but does not designate any particular company to the management (Mmereki, Machola, & Mokokwe, 2017). In this way, all the operators in the recovery chain contract under free market conditions and act in compliance with the legislation. Also, under the established objectives, companies can now bid for contracts, maybe for a particular region or county to be in charge of the management of EOLT's. Participation in the free market system is more by voluntary by the companies however strict adherence to laws regarding transportation, use, disposal and storage of EOLT's (Athanassiades, 2013). Countries under the free market system include Austria, Germany, the United Kingdom, and Switzerland.

An additional and more recent system for management of tyres is called the Hellenic system**.** This system had its origin in Greece and is named after the Greek people. In July 2014, a collective system of alternative management of used tyres was licensed and subsequently started its operations in the year 2005, existing as the only certified collective system for the management of EOLTs (Karagiannidis, Kasampalis, Antonopoulos, Perkoulidis, & Zabaniotou, 2009). This system of management includes an initial collection of EOLT's from various disposal points throughout the country, temporary stockpiling, referring to storage or warehousing by the transporters and then further transportation to material extraction, recovery and processing plants. Although the final collection of the recovery products after recycling is done in an environmentally acceptable manner in certified facilities, certain disadvantages such as prolongation of the life cycle of landfills throughout the country. Below is a chart showing the development of the Hellenic system from Jan.2005 until March 2007.

6.0 SUGGESTING AN INDEPENDENT MANAGEMENT PROGRAMME FOR EOLT IN DEVELOPING ECONOMIES

From all indications, there are products from EOLT that are of great uses in various industrial segments ranging from energy sectors to road and civil constructions as well as chemical production areas. Products from EOLT will have more value if a well outlined and monitored managerial technique is followed. This will give a clear pathway of EOLTs without having stranded wastes loitering around in our environment hazardously. For any country to have a successful Waste tyre management system development of a realistic and working middle term and long-term programme must be in place. The first step in aiming at such a goal requires a strong political will that will put in place policies and regulation that will guide such management system of choice. It is important to note that for a new EOLT management system to be well established there are five factors involved (Keefe & Fellow, 2016). These factors are depicted in the triangular shape shown in figure 6 below. It must be noted that policies and regulation form the basis and foundation for any management programme. Any sustainable waste management policy must address human and environment safety as well as social and economic compatibility of such nation (Olukanni, D.O., Adeleke, J.O. and Aremu, 2016).

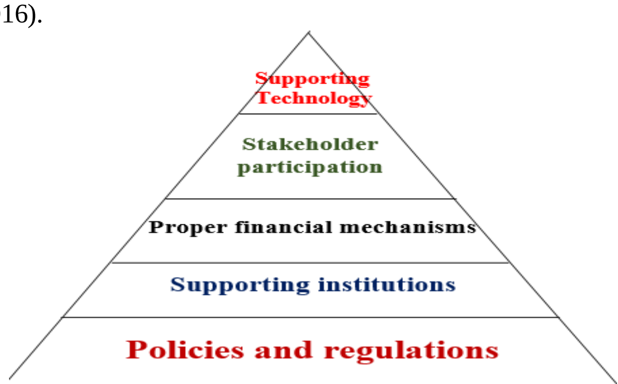


Figure 6: Pyramid of Factors involved in having a sound EOLT management System

A major and reoccurring failure root of many good policies in developing countries is frequent regime change. It is expedient that after such Waste management policies and regulation have been established using a concrete feasibility study and a pilot project to ascertain viability, a treaty should be made to make such working policy autonomous with little or no overpowering influence from any emerging government regime. After securing a sound and stable Policy, establishing an institution that will sit at the driving seat of the management programme is of a germane importance, this is the second factor itemized in figure 6 above (Duangburong, Tantayanon, & Bhandhubanyong, 2015). These institutions will create platforms for harnessing all possible resources in terms of personnel and finances to create functional departments that will see to itemized objectives and different segmented tasks at achieving the set goal of an effective and sustainable EOLT waste management. It is the function of this specialised institution to see to the participation of the stakeholders i.e government, tyre producers, private investors, end users and the recycled product market entities as well by liaising and doing business directly with all of them. The institution is also saddled with the responsibility of sitting and establishing the recycling plants as well as seeing to their running and supply of raw materials thus collection of the EOLT.

Choice of technology to be used must be done having in mind the economic strength of the country and must be a scale that will be able to break-even quickly. Using an obsolete technology or using a brand-new technology should be out of the question as these can respectively lead to an inappropriate result and the latter a white elephant project. This is what is referred to as the supporting technology sitting at the Apex of the pyramid in Figure 6. These technologies may include Pyrolysis furnaces for thermochemical operations on EOLT, (Ishola, Oyawale, Inegbenebor, & Boyo, 2018), pulverizing and grinding machines and material characterising equipment among others. The technology will definitely be industrial scale technology, strategically installed in locations that can easily be accessed by the tyre collectors. These decisions are to be made by the installed institution consulting specialist and doing a thorough cost and benefit analysis (Martínez et al., 2013). Emphasising on the need for autonomy of the EOLT waste management institutions; such action is a product of a political will to ensure that capable hands on a programme are retained and sustained in spite of the change of government regimes. Such autonomy will also be economy enabled such that the system will be self-funding after the initial funding by the establishing government during the propagating period. Once the programme is being "wined" the cost recovery mechanism takes a full course such that government input is not again needed. At this junction, the system would have been dealing directly with the public and dominating the available markets for the products as would have been established during the feasibility studies. The independent EOLT waste management institution in her bid to sustain itself will have to have cordial relationship with the public who are the major stakeholder being the "producer" of the waste; constant and unrelenting public awareness as to be able to be in full control of the use, reuse, collection and recycling of EOLTs.

6.1 Postulation 1: A "Pseudo-Producer Responsibility" Approach

Most Low Income and Lower-Middle Income countries are definitely not desirable factory sites for Tyre Industries; for obvious reasons that have to do with Economic factors that determine viable industry siting. So, these developing economies are facing double edge menace of not having access to Producer Responsibility(PR) and at the same time having a higher possibility of having to deal with a much larger number of EOLT per capital. This will be logically assumed to be so because a second-hand tyre user will most likely run through a higher number of tyres within a year or two. Tyres like any other commodity will pass through the Bath-tube Curve which means at second (or even third) hand the Life Span of such tyre is definitely closer to an end.

This postulation focuses on having a special intervention body designated to carry out the function of a PR and being funded directly (most advisable) by an additional duty on both used and new tyres at importation. While it might not be all possible to stop the importation of used vehicles and tyres there must be a certain check such that a certain age of tyres will not be allowed to leave the port. At the point of retrieval of disqualified used tyres, the rejected tyres go straight to the collection truck to convey such to the recycling site which would have been sited to a proximate location to the ports. With a body imitating the PR there will be a significant, continuous, and well-managed flow of used tyres and as a result, there will be a market for recycling tyres and recovered materials. As earlier suggested this "Pseudo-Producer" organization will enjoy a level of autonomy from the government after "maturity" though it may be reporting directly to the Ministry in charge of Waste Management.

6.2 Postulation 2: A Subsidised Liberal system

It should be noted that most often than not developing countries are faced with corruption-related issues and thus might be having some difficulties in controlling the activities at the borders. Postulation 1 cannot be successful in an economy where smuggling activities are prominent, as the solution will just make the used tyres smuggling more lucrative. This takes us to this “Subsidized Liberal System” which literarily has a blend of Government Responsibility and Liberal System (Free Market). Exactly like the Liberal System described earlier, the only significant difference is that Government will have to enter into a Public Private Partnership (PPP) with the investors, by giving a capital as Loan or issuing a debt contract with the private investors with a Pay-back modality. The government, on the other hand, will provide policies that will allow for a conducive environment for the investors. For instance, a simple law of Demand and Supply can be used to crush the business of the used tyre’ smugglers and at the same time encourage the EOLT Recycling sector of the developing country by simply removing duties on Tyres thus encouraging more inflow of used tyres which will culminate into having more EOLT to be recycled. However, caution is on this proffered system in terms of the fact that if not properly managed its fall out will result in more tyres ending up at Landfills.

7.0 Conclusion

EOLT has a potential of posing a major threat to environmental conservation and ecological well-being of any society if not tactically managed; which had been found to be the case with developing countries. The optimum aim of developing economy is to invest in any viable project that will bring an enormous profit to strengthen her feeble economy. This article extensively discussed the prospect of harnessing the economic value of recoverable materials in EOLT while at the same time proffered possible solutions to the bulk waste problem. Valuable suggestions were made on designing sustainable management templates for EOLT having clearly defined policies and regulations as the arrowhead of approaching a Techno-economic growth towards a safe recycling system. All the major stakeholders must be motivated by incentive driven arrangement and at the same time under strict monitoring and control by the inaugurated body. The measures to ensure waste tyres are recycled were itemised in order to avoid hazards associated with pilling or discarding or burning them in an unhealthy manner but rather to enjoy the wealth of recycled products.

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