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Waste Tire Management: Lebanon Case Study

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Abstract

Fast development of automotive industry and rising vehicle use is giving rise to large amount of waste tire production and generation worldwide. Tire waste management continues to be a growing crisis over most developing countries due to insufficient funding, poor infrastructure and absence of effective legislations and policy framework. Waste tire management is challenging in Lebanon due to wide use of vehicles with minimal amount of tire recycling. Being a relatively new stream of waste and with less priority from government, the waste tire management in Lebanon is at infancy stage, and needs appropriate and aggressive policies, plans and strategies. This paper investigates Lebanon's specific issues and options for a viable long-term waste tire management strategy through studying the feasibility of three different options to reduce tire waste. The three different alternatives studied are: Tire Retreading, Tire Shredding, and Tire Pyrolysis. Current practices, potential technologies, and successful systems from foreign nations were evaluated to draw conclusions and a recommendation regarding which technology is most applicable to Lebanon and which aspects of a waste tire management system needed to be newly implemented or continued to be used and improved. Taking into consideration the survey results, retreading seems an interesting way to treat waste tires in the study area.

Keywords: Tire Pyrolysis; Tire Retreading; Tire Shredding; Waste Tires

Abbreviations: ASTM: American Society for Testing and Material; CDR: Council for Development and Reconstruction; EPA: Environmental Protection Agency; EU: European Union; MRF: Material Recovery Facility; MSW: Municipal Solid Waste; TDO: Tire Derived Oil

Introduction

The industrial era has carried improvements to the quality of living human. With the rise of the industrial revolution, a noticeable transition occurred where machines and factories emerged, which helped in manufacturing merchandises. This was followed by the introduction of different waste materials, resulting from the manufacturing process, which are deleterious to our lives and environment. These wastes included tires. The problem of scrap tire became controversial in the late 1970s [1]. With the rise of the automotive industry during the mid of the 19th century, tire production gained attention. Manufacturers produced tires in the location where these tires were utilized, and when the life of tire is over, these tire wastes were stocked, resulting in public health, environmental and aesthetic problems. For example, one of the major fire hazards recorded in history was in 1999 when a tire dump in Westley, California burned for 36 days after being accidentally ignited by lightning which caused pyrolytic oil to flow and contaminate nearby streams and water bodies [2].

Tires are bulky items; their nature does not allow them to be folded to reduce their volume when being disposed in landfills. In addition, tires are not easily biodegradable [3]. Tire rubbers are made of natural rubber, synthetic rubber, carbon black, textile, steel and additives. When these tires are stockpiled, they ensure a breeding environment for deadly mosquitoes and rotten [4]. Large fraction of scrap tires is simply stockpiled or dumped around different sites where they represent hazards such as diseases and accidental fires releasing thick black smoke, resulting in public health, environmental, and aesthetic problems [5]. Moreover, major environmental problems result from open and haphazard dumping of waste tires, these actions occur regularly since there is no coordinated management plan for tire waste proper disposal.

The situation is no longer bearable at the level of human health and the environment. Haphazard dumping of tires is posing a major threat to the environment. Such waste material should be well managed and utilized. In fact, the situation requires setting clear strategies and management plan to deal with the problem. To mitigate the effects of such a serious problem, the globe should benefit from such raw material. It is of great importance to find alternatives for tire disposal and re-utilization. The use of tire waste is very important to mitigate environmental worries. Different techniques can be applied for tire recycling such as retreading, reclaiming, incineration, grinding and shredding. In addition, tires can be used in civil applications like rubberized concrete and asphalt, embankments and construction of playgrounds. Landfilling is the least desired option, suggested only when other solutions for material recycling or energy recovery cannot be applied. Tires can be efficiently used to prevent damage to landfills' cover, to avoid side-slope erosion, to protect leachate drainage piping and to allow the regular flow of landfill percolating fluids and gases [6].

The main objectives of this paper are to quantify the tire wastes produced in Lebanon from the automobile industry and to propose a national management plan to reduce tire waste through studying the feasibility of different recycling alternatives which are: Tire Retreading, Tire Shredding, and Tire Pyrolysis. Accordingly, the number of waste tires produced was estimated based on the number of cars registered in the car registration bureau, as such illegal cars are not taken into account in this study. The secondary objective presents the prices of machines and equipment required for recycling. This research does not propose a new recycling technique for tires; however, it studies the feasibility of applying the different technologies in Lebanon to get rid of tire wastes.

Methodology

Single approach method was adopted in this research. The study utilizes quantitative data collection method through a survey distributed online among participants that aims to test public awareness and engagement regarding proper tire waste disposal in Lebanon. Exactly, two hundred and twenty two participants cooperated, in which the survey distribution was not confined in a specific region or group of people. The involved participants are car drivers of different ages, social, educational and financial background. The purpose of this survey was to know whether people would accept to use retreaded and recapped tires as well as to participate in waste tire disposal program as well as accepting the use of retreaded tires to derive technically and economically attractive options to get rid of tire wastes instead of their accumulation. The data obtained from the survey was analyzed statistically using "Google Drive Docs".

In this study, waste tires generated from heavy and light trucks, bicycles, motors, and other heavy machines are not considered. If these tires are to be considered, their number has to be known to estimate the annual waste tire production. In addition, the feasibility study has to be restudied because the price of the machines and equipment differ according to the type of tire and its use. The scope of work consists of a series of sequential dependent activities starting with the study of different alternatives for proper tire waste recycling. The three different alternatives are: Tire Retreading, Tire Shredding, and Tire Pyrolysis. Then, a feasibility and economic study was conducted based on the price of machines needed for the different options for tire recycling. After studying these options, a mitigation plan was proposed for each applied technology. In addition, a detailed business plan was proposed for tire retreading. Finally, conclusion and recommendations were stated.

Local Conditions

Studies on tire waste management in Lebanon are inexistent. The proposed research is innovative because it is the first to propose strategies for decrease the amount of tire wastes on a national scale. Lebanon is a developing country that till now does not have any strategy to dispose of municipal solid waste where in some cities daily waste are dumped in open areas. The same behavior is occurring when it comes to getting rid of tire wastes. Since 1997, a private contractor was responsible for collecting Municipal Solid Waste (MSW) and tires as well through a contract with the government and separating tires from the MSW stream, which were then processed at a Material Recovery Facilities (MRF). The separated tires were shredded and disposed of at a landfill, and till now, huge amount is still being sent to landfills or accumulated at the side of roads while very few are being sent to recovery factories.

According to a study done by the Council for Development and Reconstruction (CDR) in 2012, it has been estimated that the rate of owning a car in Lebanon is one in 2.7, which is similar to advanced industrial counties. In order to quantify the number of waste tires generated each year in Lebanon, the average lifespan of a tire was considered to be around 50,000 km [7] with the average value 14,000 km travelled by car per year in Lebanon [8]. During year 2017, the number of cars has reached 1,160,445 cars, from which the waste tires produced were estimated to be more than two million waste tires annually. According to CDR, the number of passenger cars is expected to be more than 6 million by year 2020 and will reach 9 million by year 2035. Thus, the local waste tire production is heading to increase with the increasing number of the automobiles.

Despite the existence of tire shredding facilities locally, the production of tire waste still exceeds the recycling capacity; and the products derived have limited market locally; thus, the derived products are exported into nearby countries. Knowing that there are different recycling techniques to get rid of tire wastes other than tire shredding, tire retreading is not applied locally since there is no such facility in Lebanon. As for tire pyrolysis, around ten years ago a tire pyrolysis plant was open and operating however, this plant had to shut down two year ago as a result of the drop in the price of fuel locally and due to the fact that the market for the derived products was very limited.

Literature Review

Worldwide Trends

The waste tire disposal crisis is global. Regardless of the current categorization of the counties whether developed, developing and non-developed; the annual production of waste tire globally is about three billion waste tires [9]. Most of these waste tires are disposed in landfills and the rest are recycled in which the rate of production continues to surpass the rate of recycling.

For example, countries of the European Union (EU) witnessed an increase in the waste tire production between 1992 and 2005, where the production increased from 5% to 10%. The most contributors of tire waste generation are Germany, France, Italy, Spain, and Poland [10]. In 2006, a European directive wanted to ban tire disposal in landfills. This ban resulted in proper disposal of tire wastes where 41% of the tires had their material recovered and 45% ended in energy recovery programs [10]. The rates of tire recycling were based on a management system set by the countries of the European Union and vary between countries according to: the tax system of the country, the free market system, and the responsibility of the producer. For instance, Finland annual tire production is estimated to be 40,000 tons in which the whole waste tire produced is recycled and reused [11].

In Asia, industrial countries in East Asia like China and Korea are the countries that most consume rubber for tire production. For example, in China the number of waste tires produced exceeded 239 million tires in 2004 [12]. With the increase in production of waste tires in China, the government tends to make use of such beneficial raw material, where only 10% is being recycled. Developing countries in South Asia and Western Asia like India and Jordan respectively show that the generation of waste tires is less than other countries; however, still the quantity of waste generated is large. In India, about 80 million waste tires are produced annually [13]. In Jordan, the annual production of waste tires exceeds 3 million tires [14]. Western countries like the United States (US), the waste tire production reached 313 million scrap tires yearly, out these produced tires only 25% are being send to landfills [15]. In Puerto Rico, five million tires are estimated to be produced in which 80% are recycled while the rest is being disposed in landfills [16].

Methods for Tire Recycling

Retreading and Reuse of Tire

The process for tire retreading is a re-manufacturing process that allows the use of the old tire casing while a new tread is applied after the tire inspection. The "tread" is the groove that is cut on the tire surface. It ensures the friction between itself and the road surface, once the tread thickness decreases, the friction becomes less; thus, the tire is no longer used again [17]. Here comes the retreading recycling process that allows the use of the tire case and a new tread is applied. Such recycling technique helps in solving a serious environmental problem and the derived product is retreaded tire which serve vehicles.

The process of tire retreading starts with initial inspection of the tire, followed by removing of the worn treads by buffing and repairing the injuries. It consists of reconditioning a used tire by replacing the worn tread with new material. Electrical inspection is followed where an electrical current is applied to the inner cavity of the tire to check whether penetrations exist to the naked eye [18]. Then, a shearography machine is used to scan the tire from its different sides. After that, buffing process is done; the tread is removed to obtain a uniform surface in which a new retread is applied followed by repairing damages if not covered during buffing. The process continues through applying a cushion, once it is cured, which tights the new tread to the tire. Then the new tread is built, and the obtained new tread is encased to the tire followed by curing under specific temperature, time and pressure. Finally, the obtained tire undergoes final check and the operator examines the quality of the obtained product.

The benefit of this process is that the consumption of raw rubber material decreases and the life of tire are extended. According to Ferrer [19], Twenty-six liters of oil go into the production of an average new passenger car tire, while only nine liters are required for the average retread tire (34% of new). This suggests the possibility for a significant potential reduction of waste. On the other hand, tire retreading is highly dependent on the traveled distance by the tire. As the traveled distance increase the opportunity to retread tire decreases. Moreover, retreaded tires are economically feasible for passengers' cars; however, it is preferable for heavy trucks and airplanes tires. Locally, their market is limited, since most people prefer to replace old tires by new one and not retreated tires.

Challenges facing tire retreading:

- Poor image reflected about tire retreading.
- Several tire designers and manufacturers are not taking into consideration the need for retreading.
- Availability of relatively good quality tires at a low price.

Overcoming barriers of tire retreading:

- Increasing public awareness about the importance of using retreaded tires: the poor image of retreaded tires should be changed through convincing people about the safety of the tire and the amount of natural rubber preserved through using retreaded tires.
- Appling regulation for manufacturers on the type of tire that should be retreaded; like the designers of tire should make sure that the manufactured tire should be retreadable.
- Encouraging the purchasing of retreaded tires through providing high taxations on new tires and lowering the price of retreaded tires so that the customer can be aware of the gaps between the prices.
- Providing laws that determine the minimum tread depth; thus, in order for the tire to be retreaded, it should be in good condition because it is not possible to retread tires with lots of injuries. Providing legislations will be helpful in determining the tire that should be retreaded and stop the usage of the worn tire. In addition, these legislations should be well considered since they ensure public safety for those that use retreaded tires.

During tire retreading, regrooving, retreading, and other manual applications require rasping and buffing in which it creates dust [20]. The released dust contains strong rubber odor that contaminates the surrounding.

Solution: To avoid the release of the strong rubber odor and dust, certain logistic activities are required. For example, ventilation system should be installed and maintained on regular basis to remove the dust. In addition, if the dust is released in a closed environment, filters could be installed to remove fugitive odor. Applying these activities, dust and odor problem may be alleviated.

Pyrolysis Process

Pyrolysis is another method that could be applied for recycling waste. Pyrolysis concept is a thermo-chemical process that require heating waste at high temperature in an anaerobic (oxygen free) atmosphere to ensure the break of waste into smaller size [9]. Pyrolysis takes place at high temperature where the temperature ranges between 400 °C to 800 °C and the products are carbonized char and volatile fraction that are separated into non-condensable hydrocarbons oil and condensable ones. Tire pyrolysis is considered an attractive industry to dispose of tire wastes. It has minor impacts on the environment. Pyrolysis is known for its minimal air emissions because the derived gas is used as fuel during the pyrolysis process and the derived products can be easily upgraded based on their uses [21]. These derived products from the pyrolysis process are gas, liquids and solid products.

The tire pyrolysis process is highly dependent on temperature. At high temperature, more gas is produced while at lower temperature, more oil is produced [3]. Forty nine percent of oil was recovered at 475 °C having a size of 4 cm^3 where it has been realized that at temperature ranging between 400 °C and 600 °C the fuel derived from pyrolysis have the same characteristics and properties as light petroleum fuel oil. The produced gas is the one produced from the condensation of vapors in the reactor; and it is called "pyro gas" or "pyrolysis gas" which is composed of paraffinic and olefinic compounds and aromatic hydrocarbons. The produced gas is mainly hydrocarbons which are used as fuel source for engines and for producing electricity [22].

The liquid product obtained from the pyrolysis process is Tire Derived Oil (TDO). It is brown to black in color and has aromatic smell due to the presence of sulfur compounds. The oil composition varies with the reactor's conditions like: temperature, residence time and pressure. The extracted oil has to be upgraded before being used as fuel diesel substitute. The processes of oil pyrolysis are through sulfur reduction, moisture removal and distillation [21]. The pyrolysis char is the solid product obtained from the tire pyrolysis process. The components presented in the char are inorganic matter of the tire like: ash, zinc oxide, steel, silicates and non-volatile carbon black. The produced carbon black can then be reused in the process of manufacturing new tires. The obtained carbon black could vary in structure, size, chemical composition and surface area; with such variation, their application differs based on the chemical composition [23].

The thermal pyrolysis process of tires occurs in absence of air under high temperature in the reactors [24]. The produced by-products are hydrogen gas, carbon monoxide, carbon dioxide, ethane, methane, sulfur dioxide, nitrogen oxide, and other hydrocarbons. These hydrocarbons are then burned to breakdown. Gas leakage from the pyrolysis reactors may occur if these reactors are old and worn-out. In addition, strong odor may exist from the pyrolysis reactors due to the presence of hydrocarbon gases. The risk of leakage and strong odor mainly occur if the plant is damaged.

Solution: To mitigate the leakage risk and odor, regular check on the pipes must be applied to ensure that no gas leakage is taking place. As for the strong odor, it may be reduced by installing a ventilation system. Also, flaring reductions must be considered and the industry must be responsible for the amount of greenhouse gases released.

Size Reduction through Shredding

Size reduction is applied for reducing the size of waste/particles into smaller pieces. Scrap tires could be reduced into a mesh of diameter size 1 mm; also chips of 4 cm^3 are being produced as a feed for the pyrolysis operation [23]. The below presents the process for ambient tire shredding.

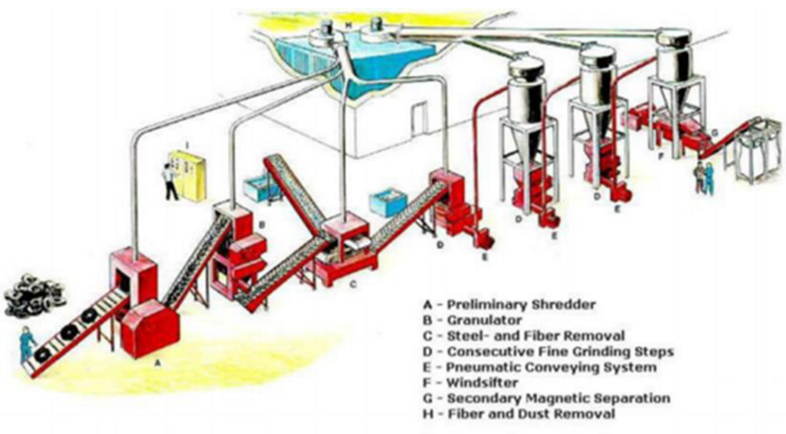

Figure 1: Ambient process for crumb rubber production [23]

In the plant layout presented in Figure 1, the tires first move on the preliminary shredder, in which tires are shredded to a mesh size of two inches. Then, the tire chips enter the granulator where their size is reduced to a size less than 4 cm^3, while steel and fibers are liberated from the rubber granules [25]. After exiting the granulator, steel is removed by magnet. The movement of materials is ensured through the conveyer belts. The final step is fine grinding, where the tire granules is reduced to a size less than 1 mm. During the operation of machines, loud noise occurs.

Solution: The noise level released during operation should not exceed the standards set by the Environmental Protection Agency (EPA). During daytime, noise level should not exceed 55 dB while during night noise level should not exceed 45 dB.

Data Analysis and Discussion

Survey Analysis

According to the data collected, little interest was recorded in the issue of using retreated tires; results showed that 38% of the tested population accepted the use of retreated tires while the remaining 62% refused using recycled tires as shown in Figure 2.

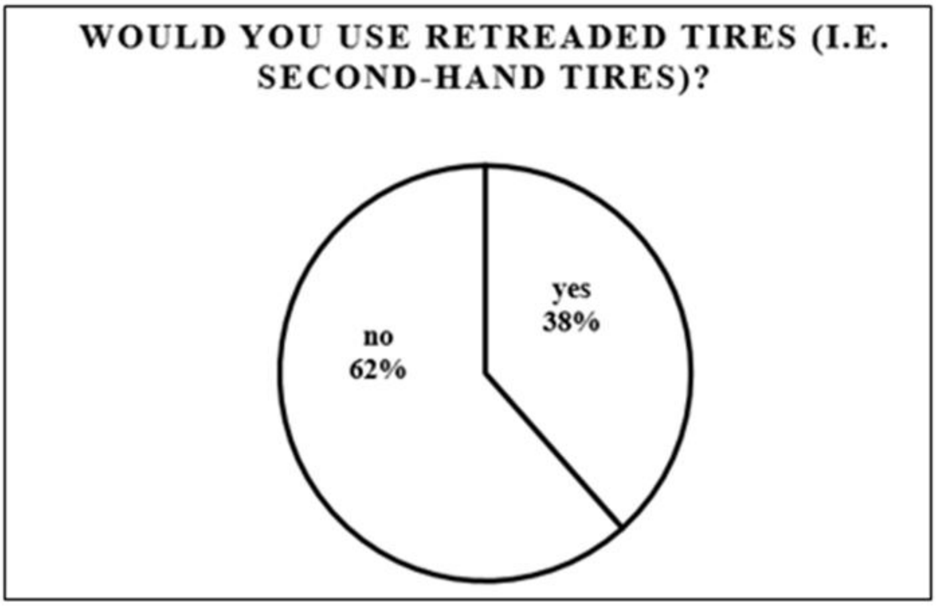

Figure 2: Percentage of people willing to use retreaded tires

From the collected data it seems that most people did not know the destination of waste tires, where about 76 % were not aware of the fate of waste tires shown in Figure 3.

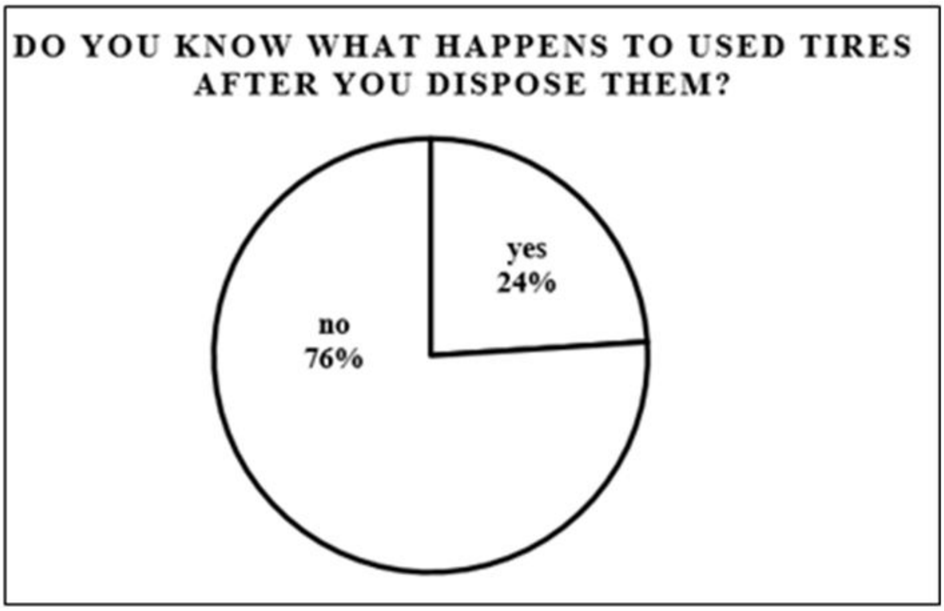

Figure 3: Percentage of people that know what happens to waste tires

Participants were asked whether they know the impacts of waste tires if not properly disposed. 60% knew the adverse impacts of waste tires on the environment if not properly disposed while the rest don't know how harmful waste tires are on human beings and the environment as shown in Figure 4.

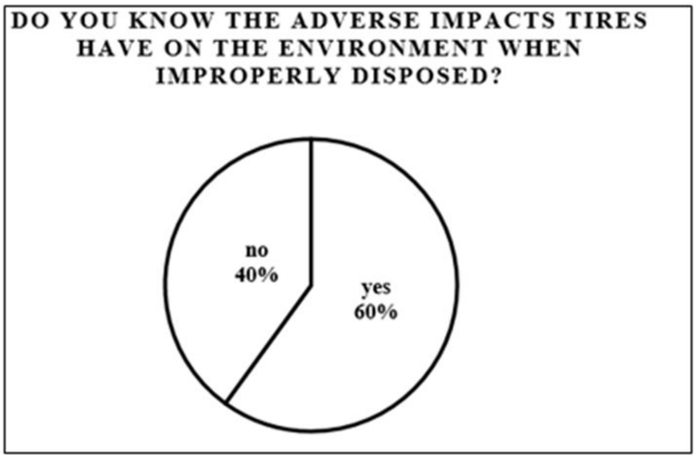

Figure 4: Percentage of people aware of the impacts of improper tire disposal

The problem seemed to be of an educational nature rather than of lack of interest because when exposed to more information about the adverse impacts of the improper management of tire wastes, a high number of the people interviewed were willing to pay for better management options. 76.4% of the interviewees were willing to pay an extra fee for the proper disposal of waste tires, and when given ranges, the majority were willing to pay between $1-20 per visit to change the four tires, 21.8% are willing to pay between $21-40, 8.8% are willing to pay between $41-60, 14.4% are willing to pay more than $60 and 15.7% are not willing to pay any cost at all as shown in Figure 5.

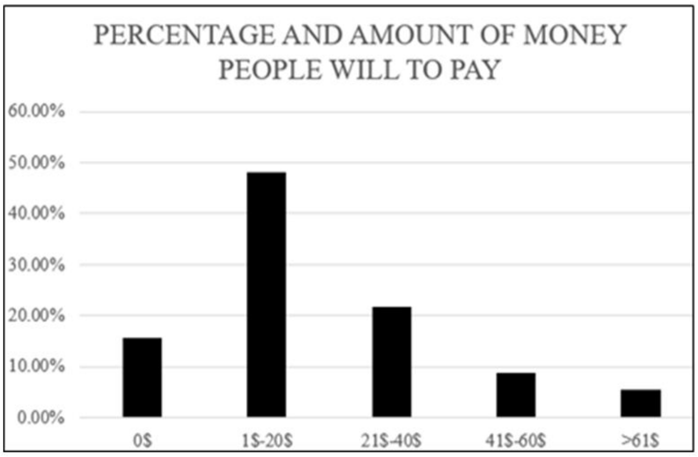

Figure 5: People willingness to pay for proper tire disposal

Moreover, a large percentage (83.3%) are willing to take their old tires to a tire recycler or specific drop-off location in case a management scheme of that kind is initiated while the rest 17% did not welcome the idea the result is indicated in Figure 6.

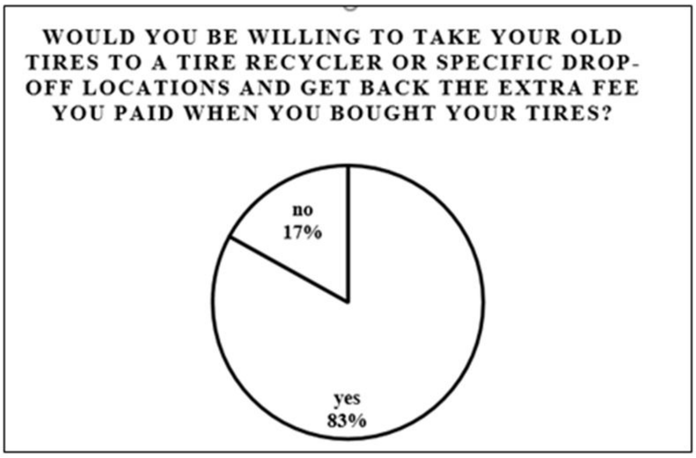

Figure 6: Percentage of people willing to take tires to a drop-off location

Data Analysis

In this study, definitive numbers were not reached due to lack of precise official data in Lebanon. Based on the United Nations the Lebanese population is 6,096,429 distributed among five localities as following: Beirut (9%), Mount Lebanon (41%), South Lebanon (18%), North Lebanon (20%) and Bekaa (12%) [26].

Based on the Lebanese Car Registration Center, the total number of cars reached 1,908,647 during 2017.
Considering the survey analysis, the following data was recorded:

- 6% tend to change their car tires for less than one year.
- 22.15% tend to change the car tires every year.
- 32.33% tend to change car tires every two years.
- 21% tend to change the car tires every three years.
- 12% tend to change the car tires every four years.
- 5.4% tend to change the car tires every five years.
- 1.12% tend to change the car tires for more than five years.

Considering the data recorded, Table 1 shows the waste tire produced in Lebanon based on the duration that Lebanese people tend to change their tires.

Tire changing during the period of	Quantity of Tires Produced
Less than one year	458,075
Yearly	1,691,061
Two Years	2,468.26
Three Years	1,603,263
Four Years	916,150
Five Years	412,268
More than Five Years	85,507

Table 1: Waste Tire Production

Tire Waste Management Strategy

To find the proper solutions to dispose of tire wastes in Lebanon, the considered alternatives above should be applicable, economical and publically acceptable. The considered alternatives should be technically beneficial, economically viable, and environmentally acceptable. Nationally, inadequate treatment and behavior are available to minimize solid wastes. Lack of human resources, absence of suitable potentials, and absence of specialized technical expertise are all responsible for ineffectual tire waste management. Different alternatives were considered to reduce tire wastes and a summary assessment is presented in Table 2. These applications illustrate the most environmentally sound disposal options and applications than can be applied for developing a national tire waste management strategy. It confirms the waste management order: reduction, reuse, and recovery. Locally, the most promising technique for proper disposal of tire wastes are recycling and reusing, since it is publicly acceptable and will not cause an additional fee for installing emission control equipment when opting for the material and recovery options.

Options	Advantages	Disadvantages
Reuse/Retread	Source & energy reduction.	Temporary solution and the use of poor-quality casings may result, in the long term, in an increase of the overall volume of waste tires.
	Increasing life span of tires.	
	Economical and targets people of low income.	Not all waste tires could be retreaded.
	A tire can be retreaded and recapped up to 3-4 times.	
The industrial & consumer market	The incorporation of rubber into sport courts providing two benefits: increased safety and performance enhancement.	Limited markets.
		Rubber tiles may curl and cause tripping if not installed correctly.
Civil engineering applications	Help preserve natural resources such as aggregates.	Rubber-modified asphalt is limited to the application for hot mix paving projects, and is not a suitable method for surface treatments.
	Rubberized asphalt has better skid resistance, reduced fatigue cracking, and longer pavement life than conventional asphalt.	
	Thermal insulation in roads to limit frost penetration.	Processing may be necessary.
	Potential for 100% for tire to be used depending on applications.	
Energy recovery	Tire derived fuel provide more energy than coal.	Costs of using tires as fuel can be higher than those for fossil fuels.
	Alternative supplementary non-fossil fuel.	May arise environmental concerns and public resistance.
		Emissions testing required.

Table 2: Tire waste management options in Lebanon

Design and Planning Consideration

The proposed recycling scheme is to have drop off centers and collection and storage facility near each proposed shredder in each major city in Lebanon. Before tire shredding and processing, procedures related to their collection, transportation, sorting and storage should be appropriately implemented. Tire collection requires logistics and planning that considers the diversity of points from where these tires are generated all over Lebanon. Knowing that tires are collected by trucks and these trucks require liquid fuel such as diesel, liquefied petroleum gas and other energy gases that all contribute in releasing carbon dioxide (CO_2), Nitrogen Oxide (NO_2) and other toxic emissions that could be trapped in the Ozone (O_3) layer causing global warming. Thus, in order to reduce the amount of emissions released, truck drivers must make sure that they are selecting the shortest road during tire collection. Also, more trees could be planted reducing the emissions released up to a certain extent. In addition, Lebanese citizens should be well educated about the benefits of delivering tires into a drop off center to ensure tire disposal in an environmentally sound manner.

Transporting used tires from the various sources of generation to facilities for sorting represents an additional burden in terms of costs, primarily in cases where distances between the points of collection and sorting are long, since tires take up a lot of space within the trucks in which they are transported. Safety during transportation is another factor that needs to be taken into account, given that good stockpiling and packaging practices are strictly followed. Sorting is necessary to separate used pneumatic tires that can be retreaded, from used tires that can be used for other applications. Sorting requires the availability of covered facilities and a specialized workforce.

Storage is also certainly a critical issue in the collection process. If the management of the overall flow is well controlled, the storage should be more of a stock in transit than permanent stock. In case the stock is to be permanent, indoor storage for tires is the best strategy to be applied because outdoor storage creates breeding environment for rats, mosquitoes and vermin. Thus, to store tires without endangering human health or the environment, the storage facility needs to meet certain requirements to prevent major risks by reducing quantity stored per unit and putting in place appropriate equipment. The following requirements shall be considered when choosing and operating a site for storing and stockpiling tires:

- Selecting an appropriate site.
- Preventing and minimizing the spread of fires (e.g., by setting a minimum distance between two cells).
- Minimizing leachate production (e.g., by covering tire piles).
- Minimizing leachate contamination of the soil and underground water (e.g., by having a compacted clay surface).

The municipalities' involvement for the proposed scheme is considered important for achieving success in the proposed tire waste management plan nationally. Municipalities could run the business through subcontractors that undertake large portion of the work applied. In addition, municipalities could implement plans and requirements that secure sustainability of recycling through source separation initiatives, by-laws, fines and general recycling awareness campaigns. The next step would be tire shredding or grinding at different grades, depending on their final application. The shredded tires would be stored in the material transfer station where potential customers could visit, view and purchase the quantity of tire shreds they require for use in their applications.

Feasibility Study and Economic Assessment

Direct comparison between the feasibility of the different technical solutions to be applied cannot be done using definitive numbers. The technical solutions are affected by several factors including product quality, market demands, tire supply, transportation cost, and labor cost. The analysis for each alternative requires accurate data. In our case, the study does not include detailed analysis; general overview is presented considering the estimated number of cars estimated tire waste production and estimated cost for every technique applied.

The proposed techniques for tire recycling are:

- Rethreading technology.
- Tire Design Fuel (energy recovery).
- Tire shredding.

Tire Rethreading Technology

The success of the retreading technology is highly dependent on citizens' perception and the market. The machines needed for tire rethreading are:

- Shearography machine.
- Buffing machine.
- Mechanical builder.
- Autoclave.
- Belt
- Envelope Machine
- Final Inspection machine.

The price of the above machines ranges between $60,000 to $80,000 depending on the capacity of the machines; the power needed and type of tire to be retreaded. Sharma (2013) reported that for the rereading of 300 passenger cars the quantity and the price of raw material is described in Table 3. For retreading 300 passenger cars it costs about $5,092, i.e. the cost for retreading a single tire is about $17. After the process is over, the retreaded tires are sent back into the market. The cost of these tires ranges from $50 to $100.

Description	Quantity (kg)	Total price (US $)
Precured retread rubber	900	4,189.20
Cushion compound	105	483
Vulcanizing solution	75	246.4
Envelope	300	82.2
Curing bag	300	90.2
Total		**5092**

Table 3: Quantity and price needed for retreading 300 passenger cars

Advancement in retreading and recapping techniques has narrowed the safety and quality gap between retreaded tires and new ones. In fact, these tires fulfill high safety standards and quality control. The safety of retreaded tires is studied by the European Economic Commission (EEC) that set standards and regulations for the retreading application to passenger car tires.

Tire Pyrolysis: Another technique that can be applied to dispose of tire waste is tire pyrolysis. The tire pyrolysis plant requires a minimum investment cost of machines between $2 million to $3 million; such machine treats up to 30 metric tons of waste tire every day [27]. The products derived from the pyrolysis process are: 50% oil, 30% Carbon Black (CB), 10% steel, and 10% gas. A tire derived fuel production system can recycle up to 30 tons/hour, which means around 30,000 tires (each 100 scrap tires = 1 ton).

The pyrolysis of 1,000 kg of scrap tires produces the following:

- 500 kg of pyrolytic oil.
- 300 kg of carbon black.
- 100 kg of steel.
- 100 kg of gases.

The derived products are then delivered into the market, the price of the products vary with the market demands. The prices are presented in Table 4 (personal communication, 2018).

Product	Cost per ton ($US)
Pyrolytic oil	$150
Steel	$46
Carbon black	$20

Table 4: Cost of products derived from tire pyrolysis

Tire Shredding: Another technique that is popular and applied over the world is tire shredding. Based on the previous generation rates of tire waste, additional facilities are needed to be constructed among the localities. Such facilities already exist in Beirut, Zahle and Mount Lebanon; where most tires are shredded then end up in landfills [28]. Additional shredders are needed to be put in service of the management plan is to cover all of the Lebanese territory. The tire shredding system consists of primary shredder, stationary screens and conveyors, secondary shredder and granulator. The investment cost for a waste tire shredding system ranges from $730,000 to $1,150,000 [29]. A detailed quote should be provided depending on several factors like: tire processing, equipment to be used, number of tires and the material derived.

The investment for the primary processing step ranges from $130,000 to $150,000 and the products derived are rubber chips of size more than 5 cm x 5 cm and their market value ranges $25 to $50 per ton [29]. If it is recommended to have rubber chips less than 5 cm x 5 cm, a secondary shredder is needed. As for the secondary shredder, the machine cost ranges between $250,000 to $500,000; the products obtained are wire free and valued $150 to $250 per ton. The size of the derived products depends on their use. For some application rubber granules are required. The cost of the granulators ranges $350,000 to $500,000. The size of the granules ranges between 0.5 cm x 2 cm and their value ranges from $200 to $300 per ton. The wires derived from the pyrolysis process are valued from $40 to $120 per ton. The price of machines, the products derived; their prices and size are presented in Table 5.

Machine	Cost per ton ($US)	Derived product size (cm)	Use	Cost per ton ($US)
Primary shredder	$130,000	5 cm	Civil engineering application	$25 - $50
	$150,000			
Secondary shredder	$250,000	<5 cm	Industrial usage	$150 - $200
	$500,000			
Granulator	$350,000	<2 cm	Surfaces	$200 - $300
	$500,000		Playgrounds	
			Rubber matts	
			Sport fields	

Table 5: Cost of machines and the products derived from the shredding process

Cheaper Chinese processing system could be available at lower prices; however, industries reported that saving made on the purchase price of lower quality equipment is quickly eroded as the wear and tear on blades and motors is high and maintenance costs for shredders can be substantial. The capacity of machine to obtain rubber chips of 12 mm is up to 10 tons/hour about 10,000 tires depending on the horsepower. As for the granulator, its capacity decreases to reach 3 tons/hour since the derived products are wire and fiber frees [30].

A flow chart for tire recycling techniques is presented in Figure 7. Based on the feasibility study, it shows that retreading is the cheapest technology to dispose of tire waste; however, locally retreading has poor image according to the survey results. In order to provide retreaded tires with a good image, people's perception about retreading has to be changed through increasing public awareness about the importance of retreading and convince people that retreaded tires are safe to use. Moreover, customers should know that retreaded tires' cost is around 45% less than new ones. Also, if retreading technology is applied, there must be regulations and specifications to be abided with. Processing of waste tires proves to be economic; however, a high initial investment is necessary for the purchase of heavy moving equipment and crumbing machines to produce all crumb particle sizes and ranges. This process may be expensive to set up but once operational and markets secured, it could be a viable business. Waste tires can also be exported from neighboring countries for processing and sold for use in asphalt bitumen.

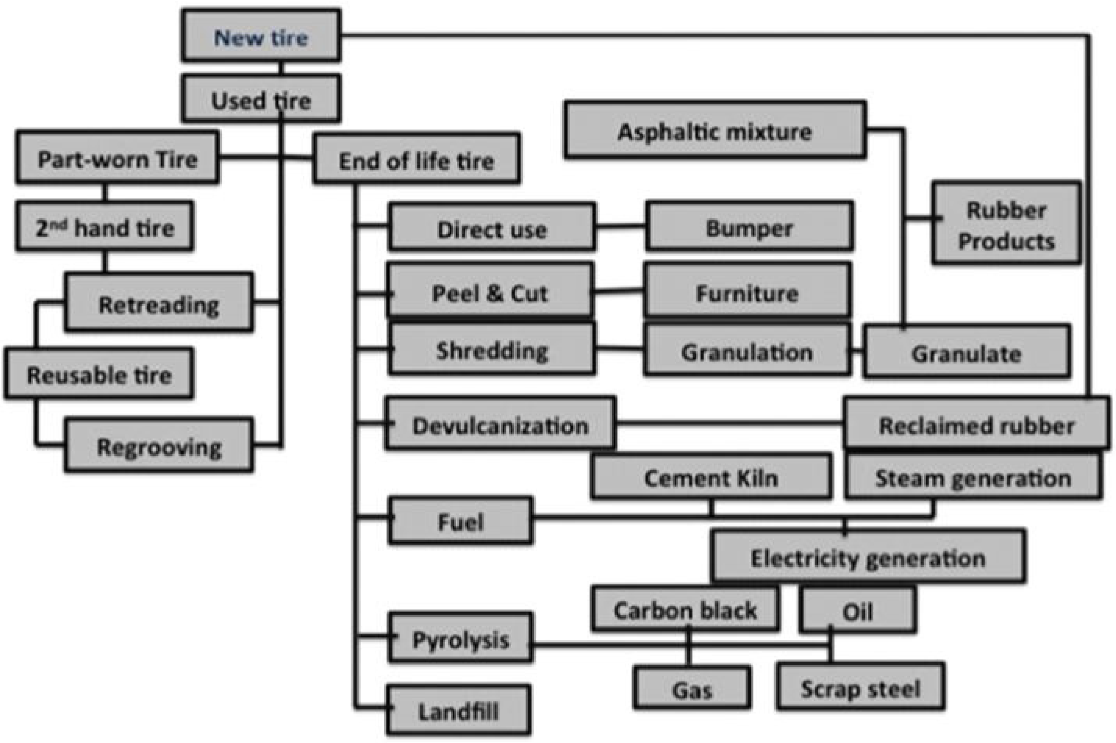

Figure 7: Tire recycling options and products derived [2]

The most expensive technology to be applied is tire pyrolysis. Such business requires high investment cost due to the need of heavy machines and reactors. For every structural facility to be built, it has to include offices and other plant equipment that need to be housed indoors as well as storage areas for waste tires for every applied technology. Finally, initial cost will include the cost of subsidiary equipment to lay the surface product. These costs can be waived if a tipping fee is imposed by the government for every purchase of a new tire, which would be used to support the management of the proposed strategy. As a result, the recycling option would be deemed more economical on the long run, and zero tire waste could be achieved.

Conclusion and Recommendations

Conclusion

Several alternatives were studied throughout this study and the recommended alternatives offers unique benefit for the different studied technologies. In fact, waste tires produced should not be perceived as "waste" instead these worn out tires should be viewed as added-value products. The different options for tire recycling revealed in this study showed that technical and economical options are useful to dispose of tire waste. Tire retreading revealed to be the recommended option to be applied locally not only because it is the most economic option but also it reduces burden on the environment since tires are made by a natural substance secreted by plants. When the waste tires are utilized again, more green areas are preserved which in return helps in balancing the ecology. As for the market of retreaded tires, these tires have their customers locally. Business speaking, with the rise of the economy crises and decrease in the purchasing power, these tires have competitive price with respect to new ones. People of average to low income are being offered a recycled tires that serve them and with the same physical properties as new ones.

Utilization of discarded tires in Lebanon would minimize impacts on the environment and human health and maximize natural resource conservation while contributing to extending the lifespan of landfills. For a successful recycling program to be implemented, the proposed strategy must ensure proper management through feasible and safe collection, transportation, storage, reuse, shredding and disposal. The conducted survey indicated that lack of awareness concerning the fate of waste tires after disposal, the current local management and disposal methods, and the adverse impacts tires had on the environment when improperly disposed. On the other hand, the participants demonstrated interest in learning and taking part in a national tire waste management scheme. Municipalities and local authorities need to play an effective role through setting an affective tire waste management and engaging the population.

Absence of adequate effective legislation led to illegal dumping of waste tires into landfills and their accumulation along the side of roads. Policies related to waste tire are not applied. The responsibility for the organization, control and management of waste tires is directly related to the authorities locally. Different recycling programs should be considered, implemented and well organized and must seek governmental support. Such programs are beneficial for developing countries to dispose of tire waste.

Recommendations

Waste tire management through open burning, dumping, and landfilling should be minimized; instead, waste tires should be recycled through retreading, grinding, shredding, and used in different civil applications, incinerated for energy, and as fuel alternative. Applying these activities will lead to economic growth and environmentally sound applications to reduce as much as possible tire waste. Each municipality should be responsible to dispose of its tire wastes produced. Cooperation with municipalities is beneficial through allowing municipalities to implement an effective system that collect, store, and transport tires to recycling facilities.

On the other hand, activation of laws, regulations, and guidelines for tire industries and setting penalties for those that fail to confirm the guidelines are a must. This will create incentives for the companies investing in finding suitable solutions for proper waste management, since positive business practices lead to economic growth locally. Increasing public awareness through expanding public participation in tire waste management system is another necessity too. The public must be informed about the importance of waste tire recycling. This could be achieved through inviting the public to attend seminars, presentations, workshops or advertisement campaigns related to waste tire recycling.

Particularly, civil engineers should benefit from the tire itself and the derived rubber products after shredding; this could be achieved through expanding the market for the derived rubber chips and granules. The tire itself could be used as lightweight embankment fill material as already approved by American Society for Testing and Material (ASTM). In addition, the obtained rubber chips could be used as aggregate alternative and the derived granules could be used as asphalt modifier. Finally, each time a customer who wants to change the tires of his cars, he could be charged to pay extra fee about $1 to $2 per tire. In this way, the extra money paid could be used for investment for proper disposal of tire waste.

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