EXPLORING WASTE TYRE PROBLEMS AND SUSTAINABLE WASTE MANAGEMENT IN THE TUNISIAN CONTEXT

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Declaration

I hereby declare the work presented in this thesis relies on my original work aside from quotations and citations that have been duly acknowledged. I additionally declare that it has not been previously or concurrently submitted for any other degree at the University of Salford or other institutions. I further agree to give permission for "fair use" copying of this thesis for scholarly and academic purposes.

Signed

Date

List of Abbreviations

ADB	African Development Bank
ANGED	Asociación Nacional de Grandes Empresas de Distribución / National Agency for Waste Management
ANPE	National Environment Protection Agency
CAC	Command and Control
CEC	Commission of the European Communities
CEDARE	Centre for Environment and Development for the Arab Region and Europe
CITET	Centre International Tunisia for Environmental Technologies
ECOLEF	Ecological packaging
ECOZIT	Ecological waste of used lubricating oils
ELT	End -of- Life Tyres
ELV	End-of-Life Vehicles
EPR	Extended Producer Responsibility
ESTs	Environmentally Sound Technologies
ETRMA	European Tyre & Rubber Manufacturers' Association
EU	European Union
FMS	Free Market System
FODEP	Pollution abatement fund [Le fonds special du trésor de depollution (FODEP)]
ISWM	Integrated solid waste management
JATMA	Japan Automobile Tyre Man Association
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MENA	Middle East and North Africa
MESD	Ministry of Environment and Sustainable Development
NGO	Non-Government Organisation
NIS	National Institute of Statistics - Tunisia
OICA	Organisation Internationale des Constructeurs d'Automobiles / International Organisation of Motors Vehicle Manufacture

PRONAGDES Programme National de Gestion des Déchets (National Waste Management Program)

REDISA Recycling and Economic Development Initiative South Africa

STIP Société Tunisienne des Industries de Pneumatiques (Tunisian Company of the Pneumatic Industries)

SWM Solid Waste Management

TDF Tyre-derived fuel

TPE Environmental Protection Tax

UNCED United Nations Conference on Environment and Development

UNEP United Nations Environment Programme

VDEQ Virginia Department of Environmental Quality

WBCSD World Business Council for Sustainable Development

WRAP Waste and Resources Action Programme

WWF World Wildlife Fund

Abstract

Waste tyres represent one of the environmentally damaging fractions of the solid waste stream in Tunisia, where the problem of inefficient waste tyre management is endemic. This is easily identified by the piles of accumulating tyre waste located on both sides of many streets and in illegal places; therefore the efficient management of this category of solid waste is important given the large quantities being generated annually. The difficulties represented by waste tyres in waste management stem from the physical and chemical characteristics of the tyres. Significant environmental problems can also arise due to improper management and disposal of waste tyres. Few studies in the Global South and even Global North countries have been carried out to assess the challenges regarding waste tyre management and suggestions for the best alternative solutions for managing this waste stream. Nevertheless, Global North countries have made progress in waste tyres management needs by implementing more efficient innovative recovery and recycling methods, and restrictive regulations regarding the management of waste tyres. However, in many Global South countries, including Tunisia, the management of waste tyres has not received adequate interest, and the processing, treatment and disposal of the waste tyres are still nascent.

In recent years, worldwide but especially in some EU countries, several measures and methods for managing waste tyres, including other principal alternatives for managing end-of-life tyres defined in the waste hierarchy, prevention, re-use, recovery and recycling, have been adopted and applied. These measures and methods are designed to minimize serious threats to both human life and the natural environment. This study attempts to establish the actions of stakeholders who have the responsibility for waste tyre management as an aspect of solid waste in Tunisia. This study also assesses and analyses important aspects of waste tyres management in Tunisia.

A combination of two methods is employed in the present investigation: qualitative and quantitative, to determine the factors influencing the effective performance of tyre waste management practice in Tunisia. Data for the present research study was gained using relevant published literature, scientific journals, academic sources, other third sector sources such as government statistical data, and research derived from governments and other agencies and field observations. In addition to the semi-structured interviews with stakeholders involved in waste management, other interviews with actors including governmental, private, academic institutions and NGOs were carried out.

The outcomes of this investigation and assessment are a wide-range outline concerning the participants that are important in tyre waste management, and a set of aspects affecting the management of waste tyres. The information provided by this study is very critical for reviewing and updating the methods and tools to update waste tyres data and trends to improve tyre waste management system efficiency and suggesting management options of recovering and recycling this waste stream that are most sustainable and beneficial to the environment from a life cycle assessment (LCA) perspective, for the Tunisian context. With relation to current Tunisia waste tyre management systems, they have to be improved by introducing specific legislation, with sustainable finance, on the disposal of waste tyres and forming schemes to oversee and manage the country's waste tyre activities. The research has enabled the researcher to produce a set of recommendations to improve the management of waste tyres in a sustainable manner in Tunisia.

CHAPTER ONE: RESEARCH INTRODUCTION

1.0 Introduction

Global population growth is increasing and is expected to rise from 7.4 billion today to 9.7 billion by 2050 (United Nations, 2017); almost all this future growth will be in the Global South, especially in Africa, Asia and Latin America (Carvalho, 2006; Gribble, 2012). Rapid population growth, along with urbanization, has contributed to increased productivity and consumption, which has aggravated waste production and accumulation, the management of which has become a major worldwide challenge, particularly in the Global South where this issue is one of the main topics for public discussion (Al-Khatib et al, 2010; Demirbas, 2011; Raco et al., 2013; Vujic et al., 2015).

The world today has changed dramatically for its inhabitants with a shift towards living in cities and these shifts have fallen in line with increases in the global population (Thorns, 2017). Lee (2015) emphasized that the percentage of the world's population in urban areas has significantly increased and the trend towards urbanization is still ongoing, citing that 54% of the world's population were living in cities in 2014, with some 70% expected by 2050. The largest increase is within cities in Global South countries that contributed to rapid urbanization and development (Grimm et al., 2008).

Mobility and transport are two of the main factors that have contributed to the shift towards urbanization, where the concentration of population and economic activity generates new demand for transport services, particularly in vehicles (including cars, trucks and buses) (Poumanyvong et al., 2012). Cities as nodal points of production depend on the supply of resources, which means long-distance transportation. Increased production and the workforce in urban areas means there is a higher concentration of transportation needs (Poumanyvong et al., 2012).

1.1. What Drives Waste Tyre Generation in the Context of Tunisia?

This study's primary context is the Republic of Tunisia, located on the Mediterranean coast of North Africa, and with a population of nearly 10.98 million people in 2014. Neighbouring countries comprise Algeria to the west and southwest and Libya on the southeast; the country has a lengthy Mediterranean coastline and Tunis is the capital city of Tunisia.

Growth in the amount of waste tyre generated in Tunisia has been driven by the evolution in transport movement, in order to strengthen its socio-economic performance; Tunisia opted

for a strategy to promote a gradual integration into the global economy by giving an important role to the transport sector in order to develop it into an efficient system with a high-quality infrastructure (African Development Bank [ADB], 2010). Linking cities to each other by transportation networks is one of the main factors that contribute to the process of development and growth in terms of social-economic aspects (Duranton et al., 2014). Tunisia itself has nine international airports with an estimated capacity of 19.05 million passengers a year, and 8 ports including La Goulette, Bizerte, Sousse, Sfax, Gabes, Skhira, Rades and Zarzis, stretching along the coastline and open for international activity (European Environment Agency 2014). In terms of the transport of goods or passengers, they are distributed on the northern, eastern and southern coasts at distances from 60 to 120 km; in addition to a road network of 20,000 km, there is 370 km of motorway and 2,256 km of railways (European Environment Agency 2014). Achour and Belloumi (2016) state that the Tunisian transport infrastructure is undergoing modernisation and renovation. Shahbaz et al. (2015) further explain that the road network has contributed to the process of movement of people between regions, and currently contributes more than 80% of the transport of goods between regions throughout the territory. Such vehicles recorded an average annual growth rate of 6.1% over the 1997-2006 period, with some 86% of this growth representing informal usage, whilst 13.5% represent heavy vehicles (Achour & Belloumi, 2016). In fact, this is due to the increase in the rate of car use (Mraihi et al., 2013). Overall, rate of passenger car ownership (cars per 1000 inhabitants) increased from 32 in 1990 to 173 in 2014 (Achour & Belloumi, 2016; Organisation Internationale des Constructeurs d'Automobiles [OICA], 2016; Abbes & Bulteau, 2018). The Tunisian statistics illustrate the evolution of fleet vehicles between 2008 and 2012, as shown in Table 1.1.

Table 1.1 The Evolution of Fleet Vehicles in Tunisia

Year	**2008**	**2009**	**2010**	**2011**	**2012**
Unit / **Vehicle Type**	**Number**	**Number**	**Number**	**Number**	**Number**
Automobiles	772315	810931	851478	894052	938755
Light Trucks	320826	336868	353711	371397	389967
Heavy trucks	75189	78949	82897	87041	91393
Tractors	128720	135156	141913	149009	156459
Others	14640	15372	16141	16948	17795
Total	**1311690**	**1377276**	**1446140**	**1518447**	**1594369**

Source : Ministère de l'Equipement de l'Environnement (MEE), (2013)

The continuous increase in the production of cars and trucks has resulted in a continued increase in the rate of generation of waste tyres (Jacob et al., 2014). In Tunisia, with a population of around 11 million, the number of cars has increased substantially in the last decade to reach over 938,755 cars in 2012. This quantity represents the number of cars registered officially, as reported by the Ministère de l'Equipement de l'Environnement MEE (2013). This amount of cars has led to an increase in the rate of accumulation of waste tyre throughout the country. However, no current official data on the amount of stockpiled waste tyre in Tunisia is available. In contrast, the estimated quantities of waste tyre generation globally are about 1.5 billion (Pilusa & Muzenda, 2016). For example, the EU produced an estimated 4.5 million tonnes of new tyres in 2010, with 289 million units of tyres being replaced per year (ETRMA, 2011). In the same way, in the United States, about 500 million units of waste tyres were generated in 2007, with about 128 million units of used tyres already stockpiled. In addition, in South Africa, about 60 million units of scrap tyres are disposed of annually across the country (Pilusa & Muzenda, 2016).

1.2. Tyre Definition

A tyre is a pneumatic covering encircling a wheel, made of natural rubber or synthetic rubber or a combination of both, whether new, used or re-treaded. It is made from the following ingredients: rubber, carbon black, silica, metal, textile, zinc oxide, sulphur, copper compounds, cadmium, lead and organic halogen compounds and some additives like solvents, age resistors, vulcanizing agents, softeners, fillers and processing aids in varying proportions depending on whether it is a car or truck tyre (United Nations Environment Programme (UNEP), 2013; Rowhani & Rainey, 2016; Mushunje et al., 2018).

1.2.1. Definition of Terms for Used Tyres or Waste Tyres

In the context of this study, used tyres and waste tyres are termed as follows:

'Used tyres' - are tyres which had been used on motor vehicles and replaced but still have an economic life (i.e. have the minimum characteristics that enables them to be used again). Used tyres are also sometimes termed as 'part worn tyres'. In other words, the used tyre has not reached the final waste stream for disposal, and may be reused, or retreaded (Limbachiya & Roberts, 2004; Nkosi et al., 2013).

'Waste tyres' - are tyres that cannot be reused for their original function and have reached their end-of-life stage, therefore needing to be disposed. The point at which a tyre becomes waste hinges on when it is 'discarded'. Waste tyres are also sometimes termed as 'part worn

tyres' that cannot be reused for the same original purpose but can be used as raw material or for energy production (Limbachiya & Roberts, 2004; Nkosi et al., 2013).

1.3. Tyre Disposal Issues and Trends of Reclamation Methods

The disposal of tyre waste in landfills causes many problems, as tyre waste occupies a large space of land and it is not biodegradable. From this point of view, the waste tyre represents a fire hazard that releases carbon monoxide and carcinogens like benzene, polluting the air with toxic smoke and contaminating the local environment as the ash settles. Based on this, many Global North countries, including the EU, have banned tyre disposal in landfills (UNEP, 2011). The waste tyres are classified, according to Basel Convention as stated by UNEP (2000), as a hazardous material, which falls under the scope of the category of waste listed in annexe 1 of the hazardous material because it contains about 1.5% by weight of hazardous substances. Table 1.2 illustrates Annex I: Constituents contained in tyres.

Table 1.2 Substances Contained in Tyres

Convention constituent	**Chemical name**	**Remarks**	**Content (%weight)**
Y22	Copper compounds	Alloying constituent of the metallic reinforcing material (steel cord)	Approx. 0.02
Y23	Zinc compounds	Zinc oxide, retained in the rubber matrix	Approx. 1
Y26	Cadmium	On trace levels, as cadmium compounds attendant substance of zinc oxide	Max. 0.001
Y31	Lead compounds	On trace levels, as attendant substance of zinc oxide	Max. 0.005
Y34	Acidic solutions or acids in solid form	Stearic acid, in solid form	Approx. 0.3
Y45	Organ halogen compounds other than substances in Annex I to the Convention	Halogen butyl rubber	Content of halogens Max. 0.10

*Estimated for a 7kg car tyre.
Source: UNEP (2000, p.2).

Reducing the environmental impact of waste tyres and increasing sustainability has become than important waste management issue, and it is necessary to address the problem of accumulation of waste stocks (Ferrão et al., 2008; Jacob et al., 2014).

In this regards, the European Council Directive 2008/98/EC defined Waste Management as "collection, transport, recovery and disposal of waste, including the supervision of such

operations and after-care of disposal sites" (European Council, 2008). Similarly, Gilpin (1996, p. 201) defined waste management as “purposeful, systematic control of the generation, storage, collection, transportation, segregation, processing, recycling, recovery and disposal of solid waste in a sanitary, aesthetically acceptable and economical manner”.

Tyre products used in the passenger car, truck and aeroplane industries are responsible for waste tyre generation in large quantities (Duangburong et al., 2015). In Global South countries, waste tyres are rarely a priority for waste stream management, meaning large amounts of waste tyres end up in the landfill or an open environment (Jacob et al., 2014). In addition, Elnaas et al. (2015) expressed that in many Arab countries, waste management is in its infancy, and is characterized by a high percentage of uncollected waste, with most of the waste directed to open or uncontrolled dumpsites. This may relate to an absence of adequate policies, clear legislation and strong regulations. Abarca-Guerrero (2015) and Ezeah (2012) suggest that many of the common barriers which hinder legal and policy arrangements in Global South countries (within Low and Middle-income countries), such as waste legislation, are fragmented into different laws, causing the lack of many important elements such as technologies and enforcement mechanisms.

However, the increase in tyre production and the expansion of vehicle use, and lack of recycling or recovery of such wastes, are major issues in Tunisia and Global South countries, which needs tackling. This drives the needs for an appropriate policy with plans and strategies to set a more sustainable system for waste tyre management (Elnaas et al., 2015; Marshall & Farahbakhsh, 2013). These challenges could be addressed through the introduction of sustainable waste management practices based on the waste hierarchy, with greater emphasis on waste prevention. Waste hierarchies (the concept is discussed further in Chapter 2) are used worldwide, including in EU member countries as an option for managing waste based on the principles of sustainability (UNEP, 2011).

A waste hierarchy ranks waste management options according to what priority is most useful to the environment. It gives top priority to preventing waste in the first place. When waste is created, it gives priority to preparing it for re-use, then recycling, then recovery, and last of all is disposal (Šooš & Ferencz, 2015).

The Global North countries, such as in the EU member countries, apply the waste hierarchy principles for tyre waste management within a wider framework of integrated solid waste management (ISWM) systems, and through using policies and strategies that emphasise

waste prevention, reuse, recycling, recovery, and safe disposal for tyre waste in a sustainable way. The policy is represented in using instruments such as Economic, Direct regulative and Communicative instruments (discussed further in chapter 2) to achieve solid waste reduction. Moreover, there is an evolution of management systems represented in the principles of producer responsibility, tax and free-market systems: these concepts are also discussed in more detail in chapter 2. These management systems have been applied in EU member states and have contributed to achieving close to 100% recovery of waste tyres (ETRMA, 2011; Sienkiewicz et al., 2012; Torretta et al., 2015). These measures are used alongside the European Union's (EU) restrictive legal regulations (Directive on the Landfill of Waste 1999/31/EC and End of life Vehicle 2000/53/EC), which prohibit stockpiling of tyres in landfills.

Although Tunisia has adopted the concept of integrated SWM (this concept is discussed further in Chapter 2) (Haouaoui & Loukil, 2009), it still suffers from the indiscriminate disposal of waste tyres. In Tunisia presently, waste tyres are disposed of in a random way, i.e. in the open environment. There are no estimated indicators of the quantity of tyre waste that is produced each year in the country or methods of their disposal, despite the trend of increasing new-vehicle registrations annually in the country, which result in an increase at the end of life tyres (ELTs) that entering disposal routes annually. Waste tyres could be regarded as a constituting threat to human and environmental health, which is found in illegal dumpsites across the country. As a consequence, waste tyres litter the country, which are uselessly stockpiled or disposed at unsuitable disposal sites and are often handled by the informal chains operated by "scavengers", recovery companies and scrap dealers. This situation is compounded by the absence of effective policy instruments in the country, such as a producer responsibility or a taxation system that represents sustainable finance with proper legislation to guide, control and regulate the disposal, storage, utilization and recycling of this "tyre waste" in a sustainable manner (GIZ and SWEEP-Net, 2014; Gargouri et al., 2016). It has been emphasised by Connor et al. (2013) that the waste tyre management systems in the global South countries are inefficient.

This research was therefore motivated by the need to fill the above gaps in knowledge by generating qualitative and quantitative data on waste tyre management as an aspect of SWM in Tunisia that could underpin future waste tyre management strategies and policies in the country. Gaps identified in chapter 2 include:

- A lack of knowledge surrounding the extent of the waste tyre problem in Tunisia, particularly around the flow of tyres and their origin, including;
- A Lack of data concerning waste tyre generation.
- The environmental burdens of waste tyre disposal have not been adequately explored and are poorly understood.
- A gap surrounding the best options to treat tyre waste in the Tunisian context; at present there is no formal system
- A general lack of academic research exploring stakeholder views towards the problem, along with potential solutions. At present there are no studies within the North African context around tyre waste management.

1.4. Research Justification and Motivation

Currently, many Global South nations are facing the challenges of managing waste tyres, a problem which keeps on growing due to increased importation of cars and tyres. There are about 19.3 million tonnes of used tyres produced annually in the world (Labaki and Jeguirim, 2017), and this figure will increase in the coming years with the expected growth of the world's motor vehicle fleet. Very often in Global South nations, there are no legal framework and industrial infrastructure to address the issue of waste tyre collection, legal stockpiling, recycling and even disposing of waste tyres in an environmentally safe and sound manner (Muzenda and Popa, 2015). Waste tyres, if not managed properly, can cause negative effects to the community and environment. Already, waste tyres are affecting the social well-being of Tunisian communities in terms of being a source of inconvenience, and distortion of the aesthetic view when dumped on the side of the roads and public spaces. Tyre waste has a potential to lead to tyre fires, which produce acid smoke harmful to humans and the environment, as well as leaving behind an oily residue. Tyre fires are not extinguishable and in some instances burn for several weeks, which are then costly. Socially, the communities do not see tyre waste as their responsibility and in this they are not willing to interfere with them (Sienkiewicz et al., 2012).

As stated above, Libya and Tunisia are neighbouring countries, and this study will provide that there is considerable trade across their border in in many different goods including tyres, some of it of an informal nature. Both Libya and Tunisia are among the countries facing this challenge of managing waste tyres, and Libya-Tunisia relations witnessed beneficial development in the political and economic process after the stalemate during the cold war,

especially after Ben Ali came to power in Tunisia in 1987 (Kirfaa, 2014). Since that time, the improved bilateral relations opened up space to allow for free movement of people and goods between the two countries (Tunisia and Libya); for example, transactions across the Ras Ajdir border became active, resulting in the so-called border trade (formal and informal). Thanks to the 1974 Union of Djerba between Tunisia and Libya, the two countries established a number of measures that were aimed at facilitating, and even encouraging, cross-border flows. The bilateral agreement allows Libyan and Tunisian nationals to freely enter both countries without a visa. The situation at the border level between Tunisia and Libya is directly inherited from the historic relationships established between the two countries and the deep-rooted connections among local communities on both sides of the border (Chauzal & Zavagli, 2016). A sizable portion of border trade between the populations of the Tunisia-Libya border region, is made up of individuals and families who often interact on both sides of the border. They may work on one side of the border, but they also regularly purchase goods and services in the other country. Border consumers are a savvy group. As exchange rates fluctuate and pricing policies evolve, border consumers and smugglers move back and forth to purchase goods and services at the best rate (Ayadi et al., 2013). In fact, gasoline, diesel and other commodities are less expensive in Libya than in Tunisia, so consumers, including smugglers, flock to gas stations at the western Libya border in towns such as Zlatan and Zuwara, in order to fill their vehicles with fuel and to purchase and smuggle many other goods subsidised by the Libyan government. Tyres (particularly car tyres) are one of the desirable commodity categories of border consumers and smugglers, and are often smuggled to the Tunisian market. From here begins the story that motivated the researcher to study waste tyres. The researcher, when in Libya, has observed that Tunisians travel to Libya in their own cars to buy a range of materials from the Libyan market, including tyres. In this regard, the Tunisian car owners are replacing their tyres with new units and leave behind their waste tyres. This behaviour causes waste tyre accumulation on the area near the Libya-Tunisia border, which represents a threat to the natural environment and human health.

This observation raises the question of why Tunisian cars owners are disposing of their waste tyres after replaced them with a new ones in Libya. In addition, is the Libyan Environmental General Authority aware of this situation? This formulated a question in the researcher's mind around: Is there a waste tyre management system in place? This issues was brought into even greater focus when the author saw that waste tyres were being burned by protesters

after the Arab Spring Revolution in 2011, both in Libya and Tunisia. For this reason, the researcher conducted a short field observation at that time and realised that the two counties, both Libya and Tunisia, have not a system in place to manage this type of waste. In light of the above consideration, the researcher started researching in order to propose a waste tyre management system to Libya, after consultation with the branch director of the General Authority for Environment, Sorman-Libya. However, after a year of work on the research, unfortunately, the researcher was forced to change the focus of the research area to Tunisia, due to the dangerous security situation in Libya. The researcher took this opportunity to go further, as an alternative option, and to investigate the reasons tyre waste management is not sustainable in Tunisia, based on predetermined questions. Since used tyres are not biodegradable, there is a strong motivation to successfully manage this fast-growing waste flow, thus mitigating its negative environmental impact.

1.5. Global North Countries, Especially EU, Provide Good Lessons that can be applied in the Tunisian Context and other Similar Countries

Global North countries have taken serious steps in the field of waste management and have experience in the successful uses of tyre waste management through various applications. Viable industries in the field of waste tyre treatment have been developed due to the adoption of effective policies and legislation since the United Nations Conference on Environment and Development (UNCED), known as the Earth Summit in Rio de Janeiro. Sienkiewicz et al. (2012) states that the legislation and environmental policies for waste tyre management adopted by the EU led to solutions enabling the sustainability of the sector. However, their use in Tunisia is very limited or negligible; it has, therefore, become necessary to know the reasons for the accumulation of waste tyres in Tunisia and to understand why the country has not so far managed to benefit from waste tyres in the same way advanced countries have.

In the literature review, the researcher focuses on the experiences of many countries over the world, especially EU member countries, particularly those located on the Mediterranean sea basin; the so-called Mediterranean Europe countries (such as France, Spain, Italy, Greece, and Portugal) in the field of waste management, and the policy of waste management, including legislation, regulations, and the systems that have been developed and implemented in these countries. Thus, many of Mediterranean Europe countries have testimonies of success in waste management, making it a good example in the context of ISWM, particularly for the waste tyre management in the context of Tunisia.

The waste management policy in the context of the EU provides good lessons that can be applied in the Tunisian context, by considering that the EU (especially Mediterranean Europe countries) is a neighbour and partner of the five Maghrebi countries (Algeria, Libya, Mauritania, Morocco and Tunisia), which share links in terms of historical, cultural and linguistic ties with Europe (European Commission, 2012), particularly colonial ties, such as Tunisia has with France (Mckay, 1945). In this regard, the EU is providing financial support for the European Neighbourhood Policy (ENP) through a dedicated European Neighbourhood and Partnership Instrument (ENPI). It targets various areas of co-operation including sustainable development and the environment, supporting jointly agreed reform priorities in the ENP Action Plans (Neubauer, 2008).

The EU concluded Euro-Mediterranean Association Agreements between 1998 and 2005 with the southern Mediterranean countries. These agreements effectively provide a suitable framework for North-South political dialogue. They also serve as a basis for the gradual liberalisation of trade in the Mediterranean area and set out the conditions for economic, social and cultural cooperation between the EU and each partner country (Spiteri et al., 2016). Thus, the EU offers the best opportunity for change to occur in Tunisia, through knowledge exchange activities linked to such agreements.

The EU is already supporting Maghreb countries and other Southern Mediterranean partners to strengthen environmental protection and the fight against climate change through a range of bilateral measures as well as through the Horizon 2020 initiative on the de-pollution of the Mediterranean Sea. In light of this, North Africa can benefit from EU-experience with different waste streams. However, the presence of heterogeneity in the region does not prevent the follow-up a step-by-step approach according to concrete “starting points” with regard to waste management within these countries could turn out to be most useful (European Commission, 2012). Moreover, (Neubauer, 2008) has emphasised that are many elements of the EU waste legislation are apt to improve the waste management situation in the Eastern and Mediterranean Neighbouring Countries and Russia.

Tunisia was the first Mediterranean country in North Africa to sign an Association Agreement with the EU, in July 1995. Tariff dismantling under the Agreement was completed in 2008, with the resulting Free Trade Area, the first between the EU and a Mediterranean partner. Recently, in April 2016, the deep and comprehensive negotiation round for the Free Trade Area took place between the EU and Tunisia. This negotiation and

its discussions covered a wide range of issues, including services and sustainable development and bringing Tunisian legislation closer to that of the EU in trade-related areas (European Commission, 2016). The EU is Tunisia's largest trading partner, accounting for 62.8% of its trade in 2015, when 71% of Tunisia's exports went to the EU. In addition, Tunisia is a part of the Euro-Mediterranean Partnership (EMP), also known as the Barcelona Process. The Barcelona Declaration contains three chapters stating that the environment is one of the priorities of the economic cooperation chapter (Lesser, 2009).

1.6. Statement of Problem

As the world now lives in a state of increasing scarcity in terms of limited raw materials from natural resources, inadequate financial resources and fertile land, final disposal of waste has become a challenge. As a result, Global North countries have followed a special approach in SWM, so that waste management has become a focal point of concern. Waste management has been defined by the European Council Directive as the collection, transport, recovery and disposal of waste, including the supervision of such operations and after-care of disposal sites (European Council, 1991). Similarly, Gilpin (1996, p. 201) defines waste management as "purposeful, systematic control of the generation, storage, collection, transportation, segregation, processing, recycling, recovery and disposal of solid waste in a sanitary, aesthetically acceptable and economical manner".

With the evolution of science, new methods have emerged in terms of management styles that deal with technical and economic aspects of waste tyre management systems, such as the application of techniques to ensure orderly collection, treatment, and disposal of waste. One of the most important styles of waste management policy followed by Global North countries is waste hierarchy. Waste management hierarchy is a nationally and internationally accepted guide for prioritising waste management practices, with the objective of achieving optimal environmental outcomes. It sets out the preferred order of waste management practices, from most to least preferred (Hansen et al., 2002). The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The proper application of a waste hierarchy can have several benefits. It can help prevent emissions of greenhouse gases, reduce pollutants, save energy, conserve resources, create jobs, and stimulate the development of green technologies (Hansen et al., 2002).

As a result of waste hierarchies, Global North countries have made great strides in the field of SWM, including waste tyre management along with advanced technologies in recycling

and recovery, technologies that are in continuous and rapid development. In contrast, Global South countries such as Tunisia are suffering from a lack of a SWM system generally and waste tyres in particular, resulting from uncontrolled disposal of such waste; this causes environmental and health damage, due to a lack of organisational, political, and financial arrangements, which leads to weakening the power of actors in the management of these facilities. In this regard, a number of studies have been undertaken in Global South countries that emphasise the serious solid waste management (SWM) challenges being faced in these countries, as stated in the literature by Guerrero et al. (2013), Harir et al. (2015), Henry et al. (2006), Khatib (2011), Njoku et al. (2015), United Nations Environment Programme (UNEP) (2013), and Wilson et al. (2013). In terms of increases of waste generation, these researchers identify factors including improper waste disposal with inadequate waste collection, lack of legislation, lack of finance and lack of organisational leadership. These are in addition to other challenges, including increasing population, rapid urbanization, industrialization, economic development and lack of involvement from stakeholders. Therefore, it is necessary for Global South countries, including Tunisia, to work on the sustainability of waste tyre management by treating these challenges that have occurred to keep pace with progress in the field of waste management.

Presently in Tunisia, there are no estimated indicators of the quantity of tyre waste that flow each year in the country or methods of their disposal (LABIDI, 2010; GIZ and SWEEP-Net, 2014). Despite the increasing trend of new-vehicle registrations annually in the country, which result in an increase in end of life tyres (ELTs) that entering disposal routes annually (Ajam, 2020). The waste tyres could be regarded as constituting a threat to environmental and human health, which is found it in illegal dumpsites across the country. As a consequence, waste tyres litter the country and are often burnt to recover the steel strap by poor and unemployed people, or it is burnt as an expression or reaction against the government by the protesters. This situation is compounded by the absence of effective economic instrument and legislation to guide, control and regulate the disposal, storage, utilization and recycling of this “waste” in the country in a sustainable manner (LABIDI, 2010; Dridi & Khraief, 2011; GIZ and SWEEP-Net, 2014; Soriano et al., 2019). This research was therefore motivated by the need to fill above gaps in knowledge by generating quantitative and qualitative data on waste tyre management in Tunisia that could underpin future waste management strategies and policies in the country.

1.7. Research Aims and Objectives

1.7.1. Aims of the Research

This research aims to critically assess tyre waste management practices in Tunisia and to propose sustainable systems to be implemented in practice.

1.7.2. The Objectives of the Research

i. To explore current practices of waste tyres management system in Tunisia and their impacts on the environment.

ii. To analyse and determine the flow and quantity of waste tyres generated annually, in order to contribute to the development of a model for waste tyre management.

iii. To evaluate the status and effectiveness of current policies and regulations in relation to waste tyre management in Tunisia.

iv. To critically assess different management options for viable long-term waste tyre management for Tunisia from an environmental perspective.

v. To provide recommendations for improving the management of waste tyres in Tunisia and similar countries.

1.8. An Outline of the Thesis Structure

This thesis investigates and evaluates why tyre waste management as an aspect of SWM remains unsustainable in the Tunisia context. The thesis contains six chapters that frame the structure of the thesis.

Chapter One: Introduction, with Eight Subsections.

The first section presents what drives waste tyre generation in the context of Tunisia. The second section presents the general definition of the waste tyres and definition of the terms used tyre and waste tyre. The third section offers some background and context of the research, starting with tyre disposal issues and trends of reclamation methods through the concepts of ISWM, waste hierarchy, and the importance of waste prevention, reuse, recycling and recovery. Also included in this section is a set of identified gaps in knowledge. The fourth section states the justification and motivation of the research by choosing waste tyres specifically and the area of study as Tunisia. The fifth section presents why the researcher focused on the pieces of literature reviewed, in particular the experience of Global North countries, especially EU member countries located on the Mediterranean Sea basin

(Mediterranean Europe countries(, which provide good lessons that can be applied in the Tunisian context. The sixth section presents the statement of the problems the study investigates. The seventh section sets out the aims and objectives of the study. The eighth section represents the main contribution of the research study.

Chapter Two: Literature Review

This chapter presents an overview of waste management situation in Tunisia, covering regulatory, institutional, financing and economic frameworks that are applicable in the Tunisian context. This chapter highlights the general introduction of major concepts in SWM, such as the concept of integrated and sustainable solid waste management, waste management hierarchy, extended producer responsibility and other instruments that support waste management, including the arguments for and against implementing EPR in Global South countries. Afterwards, it underlines what makes tyres an environmental problem in terms of their components. In addition, this chapter discussed progress and trends in solid waste policies and strategies in EU Countries and successes achieved in waste tyre sustainability. Moreover, it reviews general directions and outcomes of solid waste strategies in Global South Countries, with a focus on the current situation of solid waste problems in the MENA region, describing the main causes and barriers of the solid waste problem in Global South Countries, including the MENA region.

Chapter Three: Research Methodology and Methods.

This chapter outlines the general approach and specific techniques adopted to address the research objectives. It begins by discussing the existential and epistemological foundations of qualitative and quantitative research and arguments for and against combining the two approaches into one. The strengths and weaknesses of two opposing approaches are briefly indicated and the rationale for combining them in one study is explained. The chapter also presents the research design, methods used in selecting participants for this research, data collection, how data was analysed and interpreted, also considering the ethical concerns/issues. The chapter concludes by giving a view of the limitations of the methodology used in conducting this study.

Chapter Four: Results.

This chapter of the research results is divided into two sections:

Section one; presents the results from the interviews and fieldwork that were conducted in Tunisia, using qualitative methods to fulfil research objectives. The subsequent section

provides the role and responsibilities of different stakeholders identified during the fieldwork. The section moves to current practices of waste tyres management system in Tunisia, including waste storage, collection, disposal and impacts of the waste management system, including what policies and regulations are currently in place to manage such waste. Key challenges towards the sustainable management of tyre waste in Tunisia are identified. The section also includes quantifying the quantity of waste tyre accumulated during a period of time in Tunisia, utilising a method proposed by the researcher.

Section two; presents the results related to the most sustainable final destination for end-of-life tyres according to LCA studies, gathered by using systematic review that followed a guide proposed by Boland et al. (Eds., 2013) and Zumsteg et al. (2012).

Chapter Five: Discussion

This chapter of discussion is divided into two parts. The first part discuss the results of the interview with participants and the fieldwork. This part is structured around the challenges identified during the interviews with participants and fieldwork to achieving sustainable tyre waste management in the study area. The second part discusses the results of the management options that are most sustainable for the final destination of end-of-life tyres from an LCA perspective. These challenges are discussed with a reflection on previous studies, and recommendations presented to overcome and resolve these issues.

Chapter Six: Conclusions and Recommendations

Chapter six concludes on the main outcomes of the research and also highlights the limitations and possible future directions for research, and suggests areas for further investigation with a contribution to knowledge.

CHAPTER TWO: LITERATURE REVIEW

2.0 Literature Review

2.1. Introduction to the Country of Research - Tunisia

2.1.1. Location and Population

Tunisia is officially known as the Republic of Tunisia and is situated on the Mediterranean coast of North Africa. It is bordered by Algeria on the west and southwest (965 km) and Libya on the southeast (459 km), as shown in the map (Figure 2.1). Tunis is the capital city of Tunisia. The area of the Republic of Tunisia is 163.610 km2. Tunisia lies between latitudes 30° and 38°N, and longitudes 7° and 12°E. An abrupt southward turn of the Mediterranean coast in northern Tunisia gives the country two distinctive Mediterranean coasts, west east in the north, and north-south in the east. The population of the Republic of Tunisia, according to the latest statistics collected in 2014, is approximately 10.98 million people.

Tunisia's economy mainly depends on a range of industries, including petroleum and mining for phosphate and iron ore, the tourism industry, and light manufacturing for export, in addition to agriculture, which plays a vital role and represents 15% of GDP (Baban et al., 1999; Azomining, 2012).

Figure 2.1 Map of Tunisia

(Source: Google maps, 2016)

2.1.2. Tunis Governorate

The Tunisian Republic divided administratively into six development regions, distributed to 24 governorates as shown on the map (Figure 2.2). While, the governorates divided into 264 "delegations" or "districts" (mutamadiyat), and further subdivided into municipalities (baladiyat), and sectors (imadats).

Figure 2.2 Map shows local Governance in Tunisia

(Source: Appleman & Leidreiter, 2018)

Tunis governorate is located in the northeast of the Tunisian Republic. The capital city of Tunisia and the cities of Pardo, Carthage, La Marsa in the governorates of Ariana, Ben Arous and Manouba make up the Greater Tunis region, with an area of 288 square kilometres, and a population of about 1,056,247 people, according to statistics from 2014 (Tunisia Statistics). The centre of the governorate is located in Tunis, the capital city. Tunis governorate consists of 21 districts or "Mutamadiyats".

2.2. Concepts, Principles and Philosophies of Solid Waste Management

2.2.1. The Concept of Sustainable Development

Waste management is now seen as a segment of the broad global concern for sustainability and it clearly an issue that goes beyond national boundaries in terms of problems and possible solutions (Fagan et al. 2001). The newest concepts, principles, and thinking on the need for good waste management has emerged from the global concept of sustainable development that was presented by the Brandt Commission of 1987. This, later on, become known as the World Commission on Environment and Development (WCED) (Imperatives, 1987). The commission report pointed out that: *'Humanity has the potential to make development sustainable by ensuring that it meets the needs of the present without compromising the ability of the future generations to meet their own needs'* (Imperatives, 1987 p. 16).

This concept has a long-term, integrated and preventive approach, which has given a new direction away from corrective and isolated approaches; it calls for shared responsibilities as an alternative to the command-and-control approaches in place (Gervais, 2002). From this point, the humanitarian endeavour in all parts of the world embraced this concept as a doctrine. It was expanded and endorsed at the 1992 Rio de Janeiro, Brazil, Earth Summit as 'Agenda 21'- the document of hope that sets out the major global plan to face the challenges and overcome the ecological and economic problems of the late twentieth century (Sitarz, 1993).

In line with the Rio Agenda 21 recommendations and other international agreements, many countries over the world including Tunisia adopted the strategic framework for sustainable development. In 1991, Tunisia established the Ministry of Environment, which since its inception has pledged to ensure the country's sustainable progress and efforts to consolidate and strengthen environmental culture. Tunisia has identified since the beginning of the 1990s a set of tools and means more adapted to national specificities, the challenges facing the country and the aspirations of the population. In this context there are many legal texts that enshrine the right to a sound environment, beginning with the 1993 decree on the creation of the National Commission for Sustainable Development. Since 1996, a national action programme for the environment and development (Agenda 21 National) has been drawn up, which extended up to the period 2007-2016 (Mahjoub et al., 2020).

However, the relationship between sustainable development (providing human needs) and ecological sustainability (environmental health) appears to be contradictory. For example, in urban areas, Freire and Strein (2001) noted that, while many cities “score” well on the development of some of the new economic sectors, few succeed in building a good quality of life and in creating a city that is clean, safe, and beautiful, without major environmental hazards (Freire and Strain 2001, p. 49).

2.2.2. Concept of Sustainable Urban Development

The agenda of sustainable urban development have always been the subject of controversy between the Global North and the Global South, which depend on the "Green" or "Brown" agenda respectively. The green agenda give special importance to the health of the ecosystem, the impacts of cities on rural resources and their surroundings, and the future threat posed by urban consumption; for example, the emission of chemicals produced in urban areas into the atmosphere, causing global warming, ozone-layer depletion, loss of biodiversity, deforestation and the exhaustion of non-renewable resources. The Brown Agenda, accusing the Global North of the bias, focuses on environmental hazards and social justice and is more concerned with the immediate problems faced by the urban poor such as a safe water supply to households, and inadequate waste management. In addition to the lack of the basic services and green areas, the disposal of faecal, liquid and biological materials, as well as issues of health, crime, violence, and social exclusion (Hardoy et al., 1992; Stren et al., 1992; Drakakis-Smith, 2000; Allen & You, 2002; Post & Baud, 2003). In this regard, among Global South countries it is a commonly held belief in that the Green Agenda cannot be addressed until the urgent problems of pollution, poverty, and environmental hazards in cities today are resolved (Stren et al., 1992). The argument is not to pay less attention to global concerns, but to acknowledge that urban and global concerns are interrelated and must be addressed. Accordingly, Post & Baud (2003) attempted to reconcile the ecological (green) with immediate need (brown) by combining them with the clarification of their trade-offs. These authors suggest integrating ecological, social, economic and environmental health into a sustainable urban development plan for SWM.

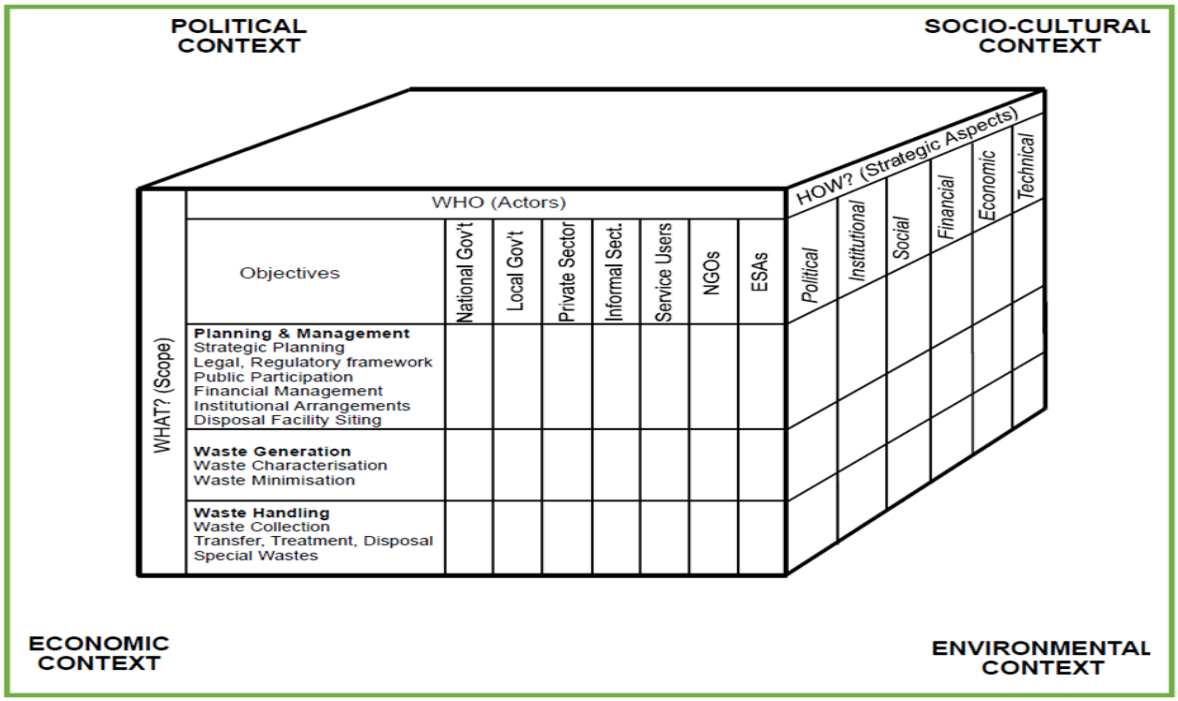
2.2.3. Sustainable Municipal Solid Waste Management (SMSWM)

The concept of sustainability has evolved through sustainable urban development into a subset: sustainable solid waste management. The main strategy is to use an approach that integrates the four dimensions of management options, stakeholders, related systems, and

driving forces, as illustrated in Figure 2.3. The fundamental principle here is to integrate and involve all sectors that are involved in SWM in order to achieve sustainable objectives.

Figure 2.3 illustrates how to integrate scope, stakeholders (actors) and strategic aspects into city-specific contexts. A special innovation is greater participation by the local population to the extent where it is recommended, through the visualization and decision of their own projects and their implementation in cooperation with the local municipal council, and not *vice versa*. This strategy is sometimes described as a bottom-up approach as opposed to top-down. Goodey (1971) justified the approach of this strategy by arguing that according to studies in environmental psychology, ego involvement through public participation leads to reduced friction, less argumentative debate, and reductions in resistance, rejection and confrontation. In this context, Tsai (2008) pointed out that the public participation is a social capital that gives people the opportunity to build meaning and vision in terms of strengthening each other in reducing waste. It has been widely recognized that waste management systems that ignore social elements are doomed to failure, thus the public participation in planning and implementation stages is equally as important as the technical and economic aspects of waste management (Carabias et al., 1999; Dijkema et al., 2000; Henry et al., 2006).

Figure 2.3 Structure of the Conceptual Framework for ISWM



Source: Schübeler et al. (1996, p. 17).

The issue of waste is considered one of the central points that is mentioned in several chapters of Agenda 21, as a cause of environmental problems that result from human activities. However, chapter 21 of Agenda 21 deals straight with the sound management of issues related to solid waste. Solid waste is also discussed in other chapters that are closely related to waste such as that mentioned in chapter 4 (changing consumption patterns), chapter 5 (population dynamics), chapter 6, (protection and promotion of human health conditions) and chapter 18 (protection of fresh water) (United Nations, 1992). Agenda 21 recommends a framework for required action that is founded on a hierarchy of objectives and focused on the four major waste-related programme areas, as follows: waste minimisation, maximisation of waste reuse and recycling, promoting environmentally sound waste disposal and treatment and extending waste service coverage (United Nations, 1992). The agenda further notes that these four programme areas are interrelated and mutually supportive, and must therefore be integrated in order to provide a comprehensive and environmentally responsive framework for managing solid wastes.

2.2.4. Overview of Solid Waste Practices in Tunisia in accordance with the conceptual framework for ISWM

Tunisia is situated in the MENA region, where SWM is considered as a major environmental challenge (Abbas et al., 2017). Its developing population and rapid urbanization generate

massive quantities of solid waste. However, the infrastructure is not sufficient to cope with the problem. In addition, local governments in Global South countries are not able to provide these critical public services effectively (Khatib, 2011). The municipalities have commonly assumed responsibility for the collection, transfer and disposal of waste generated (Srivastava et al., 2015).

In Tunisia, as in several countries within the Arab region, up to 50% of the waste generated goes uncollected, the waste that is collected is mostly mixed (Abbas et al., 2017) and only a small number of sorting and recovery initiatives exist. The typical method of disposal for municipal waste is dumping, which is a process lacking the basic measures of collection and treatment (Negm & Shareef, 2019). The inability of the current SWM systems to manage the rising waste generation rates has led to vital health and environmental issues in most Arab countries (Abaza et al., 2011). Indeed, tyre producers in Tunisia and in the Arab region generate large amounts of solid waste. For example, Zoorob and Al-Bahar (2018) stated that in Kuwait the largest waste tyre dump, located at Rehaya, holds approximately 28 million whole tyres in a chaotic fashion, whereby some of the old burial pits are in excess of 20m deep. However, there is a dearth of research published in these areas on waste tyre management. Many Global South (underdeveloped and developing) countries, especially African countries are still on a slow lane in advancing their ELT management and harnessing of the resources within ELT (Ishola et al., 2018). In Tunisia, there is lack of data onto the levels of waste tyres being generated with the absent of the legal framework specific to waste tyre management (LABIDI, 2010; Ayadi, 2015; GIZ AND SWEEP-NET, 2014). Recently there has developed a global concern for waste tyres management in terms of proliferation of environmental sustainability plans that address the problems of waste tyre disposal. Therefore, Tunisia and other less developed parts of the world must learn from the experiences.

The Tunisian culture links environmental questions fundamentally to cleanliness and to the quality standard of the SWM services provided, particularly related to waste collection. This question specifically concerns Tunisian citizens in terms of their standard daily life. In addition, they are paying greater attention to waste management services quality as they consider these services part of the face of Tunisia presented to tourists, because Tunisia depends on its tourism sector, which is considered as the main generator of jobs, prosperity and national income.

Many other environmental issues are in question in Tunisia and are associated with the deterioration and lack of water resources (Soula et al., 2020). These include: degradation of the coastal areas (Price et al., 2014), soil degradation, air pollution, and loss of biodiversity, all of which have been associated, to different extents, with climate change. Since the revolution, Tunisia has confronted critical political and economic crises, alongside which, after the revolution, there has been an annoying degradation in SWM management, in both urban and rural areas, which manifests itself through the proliferation of solid waste in landfills. Several events occurred that have contributed to the degradation of the environmental status, and to the increase in use of landfill in many regions of the country. The reasons are a multiple and are on numerous levels; for instance, the dissolution of municipal councils and their substitute by special delegations, the dissolution of rural councils for gathering and transporting the waste, tremendous damage to municipal premises because of social demands, protest movements and repetitive strikes by municipal workers demanding to increase in wages and improvements in working conditions, closure of transfer centre facilities and landfills by neighbours who live close or around these facilities, an adverse financial position nationally and the overall absence of responsible behaviour by citizens, characterized by the absence of eco-citizenship (Loschi, 2019). Formally, the Tunisian constitution of 2014 for the first time included articles relating to environmental protection and the promotion of sustainable development. However, at an institutional level, in 2014, the Ministry of the Environment was combined with the Ministry for Equipment, Housing and Territorial Development., which means that now the Minister of Environment post no longer exists and instead the under-secretary of the Ministry of Equipment fulfills this role. This situation has exacerbated environmental protests around Tunisia (Ferchichi, 2014; Loschi, 2019).

2.2.4.1. Current Situation of Solid Waste Management (SWM) in Tunisia

The SWM sector in Tunisia has been recognized as an important and vital policy area in general efforts undertaking to enhance and improve the country's living conditions. One of the most visible effects of the 2011 uprising in Tunisia had been mountains of uncollected rubbish throughout the country, both in the rich and poor neighbourhoods. As a result, the situation has become familiar to all citizens (Loschi, 2019). In Tunisia, rapid population growth along with urbanization has contributed to increased productivity and consumption, which is the most common cause of the SWM crisis (Chaabane et al., 2019). In fact, urbanization has been shown to promote economic growth and improve the livelihood of

people, but it can also increase environmental pollution, such as mismanagement of solid waste. In this regards, Bakari et al. (2017) studied the correlation between the negative effect of pollution and economic growth in Tunisia. The study concludes economic growth and the environment are linked, because all economic activity is based on the environment. The results indicate that after an interval of years, indeterminate pollution will negatively affect economic growth. Therefore, the Tunisian State needs to demonstrate economic policies and instruments to protect against the worsening of the future effects of pollution. These policies and strategies are unlikely to end pollution definitively, but at least reduce it to the minimum level. Meanwhile, Jebli et al. (2015) recommend that Tunisia should use waste in energy generation, as this eliminates wastes from tourist zones and increases the number of tourist arrivals, leading to economic growth.

Recently, Tunisia has realized that its SWM status does not fulfil its sustainable development targets and decided to shift toward a system of ISWM. Despite the efforts made by the authorities, SWM still faces many challenges in Tunisia, such as the lack of legislation, lack of financing, lack of human resources and knowledge, lack of availability of primary data in term of SWM, inappropriate technologies, the influence of the informal sector, different reports that give different values and projections, and the indifference of civil society, which are the main common issues with regards to SWM facing Tunisian decision-makers (Loschi, 2019; Chaher et al., 2020). Reports by Loschi and Chaher at al. indicate that many reforms in Tunisia still need to be targeted in terms of policy, strategy, institutional set-up, legal framework, private sector participation and integrating informal markets into the formal economy. In fact, urgent action is required to set up an integrated system for SWM that includes a tyre waste management system for Tunisia. According to the report published by GIZ and SWEEP-Net (2014), in 2012 Tunisia produced more than 2.423 million tons of solid waste, of which the deposit of waste tyres represented about 15,000 tons/year (about a million units) and the final destination of these products is not well known. In the same context, in June 2019, the World Wildlife Fund (WWF, 2019), an environmental pressure group, published a report about plastics pollution in Tunisia, urging its government to priorities "improving waste management capacity and monitoring, and encouraging consumers to reduce consumption." According to the report, titled *Stop the plastic flood, a guide for policymakers in Tunisia*, in 2016 the country recycled only 4% of its plastics waste, with 76% discharged into landfill or open dumps. Much of the plastic waste flows into the Mediterranean Sea, and the WWF estimates around 80,000 tons of this ends up in Tunisia's environment each year "due to challenges with waste management." Despite its involvement

in waste generation, the informal sector also plays the main role in waste collection for most waste generated. For instance, waste packaging from the paper and cardboard industry remains an informal sector; it offers at least 5.000 jobs throughout the country, and this applies also to tyre waste, where the management of this sector remains to this day informal (GIZ and SWEEP-Net, 2014).

2.2.4.2. Regulatory and Legal Framework

Waste management has always been one of the strategic pillars in the environment policy of different governments in Tunisia. The longer-term orientation adopted by recent administrations is designed to enhance and to actualize the environmental framework, and to protect the environment. From the legal aspect, this policy has led to a different set of regulations developed since 1975. The following are the main relevant laws and decrees worth mentioning in this respect (Dridi & Khraief, 2011):

- The cornerstone legislation on the Communities entrusting waste collection in communal areas to municipalities was enacted in Law 1975-33 of 14/05/1975.
- The cornerstone legislation on waste control and its management was enacted in Law 96-41, dated 10/06/1996: amended by the Law 2001-14 of January 30, 2001, on waste control, management, and disposal.
- The legislation on establishing the pollution abatement fund (FODEP) was enacted in Law 92 – 122.
- The legislation on the code of local taxation was enacted in Law n°97-11, of 3 February 1997.
- Decree N° 2317-2005 of 22/8/2005: Establishing a national agency for waste management and establishing its mission, administrative and financial organization, as well as the modalities of its operation.
- Decree 726-1989 of 10/6/1989: on rural councils (in charge of waste management within the territorial limits).

It is far to be referred to that chapter 12 of Law No. 41, of 10 June 1996, concerning waste control, management, and disposal, indicates that:

"Professionals must undertake to create, on their own initiative or at the initiative of the competent authorities, systems for the recycling and re-packaging of waste and for its re-use, recovery and valorization. Producers, manufacturers and suppliers shall be required to participate in any scheme to collect, transfer or to valorize certain kinds of waste and

canning waste. The competent authorities may, under the conditions stated by them, enforce the delivery of such waste or any other waste to the institutions or interests designated by them and under the conditions laid down by them."

Additionally, Chapter 9 of same Law No. 41 of June 10, 1996, also emphasizes:

"The producer, manufacturer, or carrier is responsible for the recovery of waste that is generated by the materials or products manufactured or marketed by them. The competent authorities may additionally request them to remove such waste and, wherein appropriate, contribute to recovery and removal scheme from other similar products."

Furthermore, there are frameworks that are specific to particular types of waste. In this regard, the specific frameworks form the sectors, which are defined according to the types of waste of a homogeneous composition or nature and their approved remedy procedures. Establishing the sector requires identifying the following four components:

1. The regulatory component that describes the nature and characteristics of waste in the sector

2. The institutional component that specifies the various political institutions engaged in the management of the sector

3. The technical component that determines the intervention conditions for the collection and remediation of the waste in the sector

4. The financial component that identifies the sector's funding method to ensure its sustainability. A sector should be capable to generate added value irrespective of any subsidy and be self-financed. The current sectors at present are described in the following table, 2.1.

2.2.4.3. Financing and Economic Factors

Tunisia central government is participating in finance waste management through the state budget and from international support in the form of subsidies and grants in order to develop infrastructure via National Agency for Waste Management [Asociación Nacional de Grandes Empresas de Distribución (ANGED)]. Municipalities cover recurring costs like maintenance and private sector contracts. Moreover, Municipalities also finance the collection and transport of waste to transfer stations and landfills. The municipal resources are collected via local taxes, where the rate of recovery represents only 27% (GIZ and SWEEP-Net, 2014).

Table 2.1 Illustrates the Legal Framework Specific to Waste Management Sectors

Sectors	Frameworks		
	Regulatory	**Institutional**	**Technical**
Plastic Packaging or 'Ecological packaging' (ECOLEF)	Decree No. 97-1102 of 2 June 1997	• National Agency for Waste Management [Asociación Nacional de Grandes Empresas de Distribución (ANGED)] • Ministry of Finance	• ECOLEF Program • Private Collectors • Collectors within the framework of mechanisms 32 & 41 for job creation • Routing to the ECOLEF point
Ecological waste of used lubricating oils 'ECOZIT'	Decree No. 2002-693 of 1 April 2002	ANGED	• Management assigned to the national company SOTULUB in the context of an agreement with the ANGED • Process of oil regeneration by fractioned distillation • Mode of material and energy valorization • 11 subcontracting collection companies of SOTULUB
Accumulators 'ECO-Batteries'	Decree No. 2005-3395 of 26 December 2005	ANGED	• Starter lead accumulaors: two accumulator producing companies • Physical chemical treatment of acids • Treatment of slags by recasting • Collection through outlets
Used batteries 'Eco-Piles'	Decree No. 2005-3395 of 26 December 2005	ANGED	• Collection initiative undertaken by the ANGED • A company for alkaline batteries not yet operational
Tyres	Not developed yet		• Five companies set up, including only two operating •Collection by own means without any particular organization •Problem of scattered deposit
Electrical and Electronic equipment	D3E fee currently under study	ANGED	• Dismantling and sorting • Export of the metal component • Recycling of the plastic components

Source: (GIZ and SWEEP-Net, 2010; 2014)

State resources for financing projects and activities related to the protection of the environment are derived from the Environmental Protection Tax (TPE). This tax goes to two special public treasury funds: the FODEP and the Clean Environment and Cities Aesthetics Fund. The TPE was established by Law 2002-101 of 17 December 2002 laying down the Law on Finance for the year 2003, which extended its scope to the Law on Finance for the years 2004 and 2005. It is paid on the by-products of producers and importers who utilize such products as inputs for finished products that cause environmental pollution. The above-mentioned laws set out the lists of products subject to TPE. With reference to the products subjected to this tax, a 5% value is applied to the turnover, excluding VAT, of the locally manufactured goods and on the customs value of imported goods. The total TPE resources are divided into 70% for the FODEP and 30% for the Fund for a Clean Environment and the Aesthetics of Cities. In addition to tax source, the state fund FODEP through sources such as international grants and loans, state budget allocations, the amounts from loans repaid to this fund and any other resources that may be allocated to this fund in accordance with the legislation in force. With regards to the Fund for a Clean Environment and the Aesthetics of Cities, there are other sources on top of tax that feed into this fund, represented in the following: tax stamp fee collection on the procedure of issuing national passports, tax stamp due on technical visit certificates for transportation vehicles and 50% of the resources of the tax for the Fund for National Housing Improvement (Dridi & Khraief, 2011; GIZ and SWEEP-Net, 2010; 2014).

In spite of the development of regulations, their enforcement and the creation of TPE, Tunisia fails to use (appropriate) economic instruments to reduce solid waste. In this regards, Chaabane (2020) stated that Tunisia's finance system for waste management is mainly characterized by the absence of financial incentives and effective cost recovery mechanisms. The failure to utilize (appropriate) economic instruments to reduce solid waste seems to limit the incentives for firms to recycle beyond what is beneficial to them. As an example, Chaabane (2020) points out that the external costs of landfills are not internalized. The use of economic instruments to manage solid waste requires an integrated approach to waste management and a reduction of uncontrolled landfills. Compared to uncontrolled landfills, controlled landfills are a costly but necessary option to limit spillovers and ensure sustainable development (Dridi and Khraief, 2011). Table 2.2 highlights the financial support mechanisms utilized in the management of a range of different waste streams.

Table 2.2 The Financial Support Mechanism Utilized in The Management of Some Different Waste Streams

Waste Type	Finance Mechanism
Financing for hazardous industrial waste management	For the management of hazardous industrial waste, the state fully supports investment for the construction of treatment facilities, while operating costs are assumed equally by the waste producers (50%) and the state (50% from environmental taxes).
Financing for medical waste management	The project management of medical waste is funded by the World Bank, while the operating costs are funded by the waste producers, including public healthcare establishments (Etablissements de soins publics (EPS) and private clinics).
Financing for green and agricultural waste	The municipalities provide collection of green waste in communal areas, the producer participates in removal costs, the public, i.e. the state, assumes all costs when the waste is unknown.
Financing for packaging waste	The financing of the sector is supported in part by the private sector and in part by the state (FODEP), ANGED currently is responsible for operating several ECOLEF centers and subsidizes plastics collection and transportation.
Financing for construction and demolition waste	Local communities bear the costs of disposal of demolition waste, as the waste is usually discharged by the citizen or transporters in public places, in vacant lots, on roadsides, or in waterways.
Financing for waste tyres	The private sector supports all costs of collection, transportation, storage and treatment of waste. ANGED proposes to launch a study on the feasibility of setting up an Eco-tyre industry and the introduction of an environmental tax (eco-tax).
Financing for oil and lubricants waste	The financing of this sector is provided by Eco-taxes on imported oil. Indeed, there is a levy on importers of 5% on the import value of oils, plastics and other products.

Source: (GIZ and SWEEP-Net, 2010; 2014)

2.2.4.4. Institutional Framework

The current Solid Waste Management (SWM) institutional framework and responsibilities in Tunisia are under revision and development. Current framework and responsibilities for SWM are illustrated in Table 2.3.

Table 2.3 Illustrates Institutional Framework and Responsibility

Institutions	Tasks/Responsibilities
National level	
Ministry of Local Authorities and Environment (MLAE)	• Preparation and leadership of the national policy on environmental protection • Development of regulations related to environmental protection • Supervision authority over municipalities and regional councils
ANGED	• Participation in the development of the national strategies and SWM programmes • Implementation of projects and investments in the field on the account of the State • Infrastructure operations, transfer facilities and landfills for non-hazardous waste • Exploiting hazardous waste treatment infrastructure • Providing technical assistance to municipalities and industries in SWM
National Agency for Environmental Protection (ANPE)	• Control and enforcement of the regulations on SWM
Ministry of Finance	• Participation in the development and implementation of financial instruments for SWM and related tax recovery
Ministry of Public Health	• Participates in the development and conduct of SWM programmes related to the public and private health sector
Ministry of Industry	• Participates in the development and implementation of programmes related to waste produced from industrial activities • Assigns operating permits for installations classified unhealthy and uncomfortable
Ministry of Trade	• Participates in the development and conduct of programmes related to waste produced from commercial activities
Ministry of Agriculture	• Participates in the development of regulations to protect the environment against pollution caused by SWM operations • Encourages composting initiatives
Local level	
Municipalities	• Collection and transportation of municipal waste to transfer stations • Legal framework at local levels • Infrastructure for waste collection, sorting, composting • Awareness programmes.
Environmental Police	• Control and enforcement of SWM laws

Sources: **(**Boudra, 2014; GIZ and SWEEP-Net, 2010; 2014).

In fact, waste management is a shared responsibility between several stakeholders on the national and local level. The key officials involved in the waste management responsibilities are:

- At national level as directly involved: Ministry of Local Authorities and Environment (MLAE) (Formerly Ministry of Environment and sustainable development [MESD]), National Agency for Waste Management (ANGED), while the Ministry of Industry and the Ministry of Finance etc. are to a lesser degree involved in the system of waste management. Table 2.3 describes related ministries and agencies and their respective roles in waste management system, with the tasks most likely to overlap:
- At the local level, the municipalities are the governing body in charge of waste management, as stipulated by the law No. 96-41 related to control, management, and disposal of waste;
- Waste producers under the framework of Law N° 96-41 (Polluter Pays) are also responsible for waste management: this is represented in the different waste recovery systems such as ECOLEF, ECOZIT, ECO Batteries, etc., as listed in table 2.1 (Mahjoub et al., 2020; GIZ and SWEEP-Net, 2010; 2014)

In Tunisia, Municipalities (urban and rural areas) are the main authorities responsible for SWM operations in terms of the collection and transportation of the collected mixed waste to the transfer stations, while ANGED are responsible to transport waste from stations to landfill and managing it. Moreover, ANGED affiliates are responsible for the collection and recycling of packaging materials, used oil, and batteries. In industrial areas, the Groups of Maintenance and Management (GMGs) are liable for collection and transportation of non-hazardous wastes in industrial areas, operating as associations to organize activities around the industrial area in order to ameliorate the quality of life and to rehabilitate the contaminated sites (Mahjoub et al., 2020).

2.3. General Introduction of Major Concepts in Solid Waste Management (SWM)

The global goals of SWM are to protect environmental and human health, promote the quality of life, support the efficiency and productivity of the economy and generate employment (Schübeler et al., 1996). Despite increasing policies and strategies put in place to achieve these goals, success remains elusive, as net solid waste generation continues to increase in volume and variety. Thus, waste reduction with an emphasis on prevention is increasingly becoming a major policy focus in all countries. The ways by which SWM is conceived, planned and executed, including the principles and policies that govern such frameworks, is a complex issue and vary in space, contexts and time; yet it is possible to speak of common models and general management principles. This chapter examines the

major concepts; principles and strategies applied in SWM, in particular tyre waste management, in major regions of the Global North, specifically in European member states, but their outcomes are reviewed in the next chapter.

2.3.1. Integrated and Sustainable Solid Waste Management (ISSWM)

Solid waste specialists realize that the best way to reduce pressure on disposal systems is to reduce the amount of waste produced. The focus of modern Solid Waste Management (SWM) is on reducing, reuse, and recovery before disposal. These three words are at the heart of the discussion of integrated waste management systems. Integrated solid waste management (ISWM) is defined as "selection and application of appropriate management techniques and programs to achieve specific waste management objectives and goals" (Daniel & Laura 1999, p. 18). This concept provides a systematic analysis of all issues related to sound waste management, including technical, socio-economic, financial and administrative capacities of city councils, environmental and political aspects and the socio-cultural context.

The concept of Integrated Waste Management (ISWM) was developed by WASTE and was first presented at the "Ittingen Workshop on Municipal Solid Waste Management", held in Switzerland, April 1995 (van de Klundert & Anschütz, 2000). ISWM seeks to integrate stakeholders, system elements and aspects (Figure 2.4), so as to meet objectives or to arrive at sustainable results (Wilson et al., 2013).

The guiding principle is to embrace the philosophy of ISWM, which recognises that " there is no single practice that is always preferred over others, rather to consider the full range of waste streams to be managed and views the available waste management practices as a menu of options through which the preferred option can be selected based on environmental and economic considerations of the site (Morrissey & Browne, 2004, p. 298) , or that ISWM is ‘not a package solution' (Zurbrugg, 2002, p. 11).

In the context of overall conditions for sustainability and ISWM in the Global South countries, Bulle (1999) from his WASTE experience, suggests such area should select options as follows:

- Combining together the private, public and community sectors and give them specifically defined responsibilities in various fields, from preliminary collection to waste recycling.

- Integrate especially adapted technologies into the sector (from source separation to the initial collection until recovery), thus giving rise to generating income and jobs.

According to Van de Klundert & Anschütz (2001), ISWM concept takes as a starting point four basic principles:

- Equity: All citizens (irrespective of their social or economic status) have a right to obtain an appropriate waste management system for reasons of environmental health.
- Effectiveness: The applied waste management model will result in the safe removal of all waste.
- Efficiency: All waste is managed by maximizing benefits, reducing costs and optimizing the resource utilisation, taking into account equity, effectiveness and sustainability.
- Sustainability: the waste management system is suitable for local conditions and is feasible from a technical, environmental, social, economic, financial, institutional and political perspective. That is, it can sustain itself over time without exhausting the resources on which it relies. Van de Klundert and Anschutz (1999) explain further the terms "sustainable" and "integrated" as used in SWM concepts to confirm the need for their localization and self-maintenance over time without compromising existing and future resources. They have expanded concepts thus:

Sustainable, a system that is:

- Suitable for local conditions in which they operate from a technical, social, economic, financial, institutional and environmental perspective,
- Able to maintain itself for a long time without underestimating the resources it needs.

Integrated, a system that:

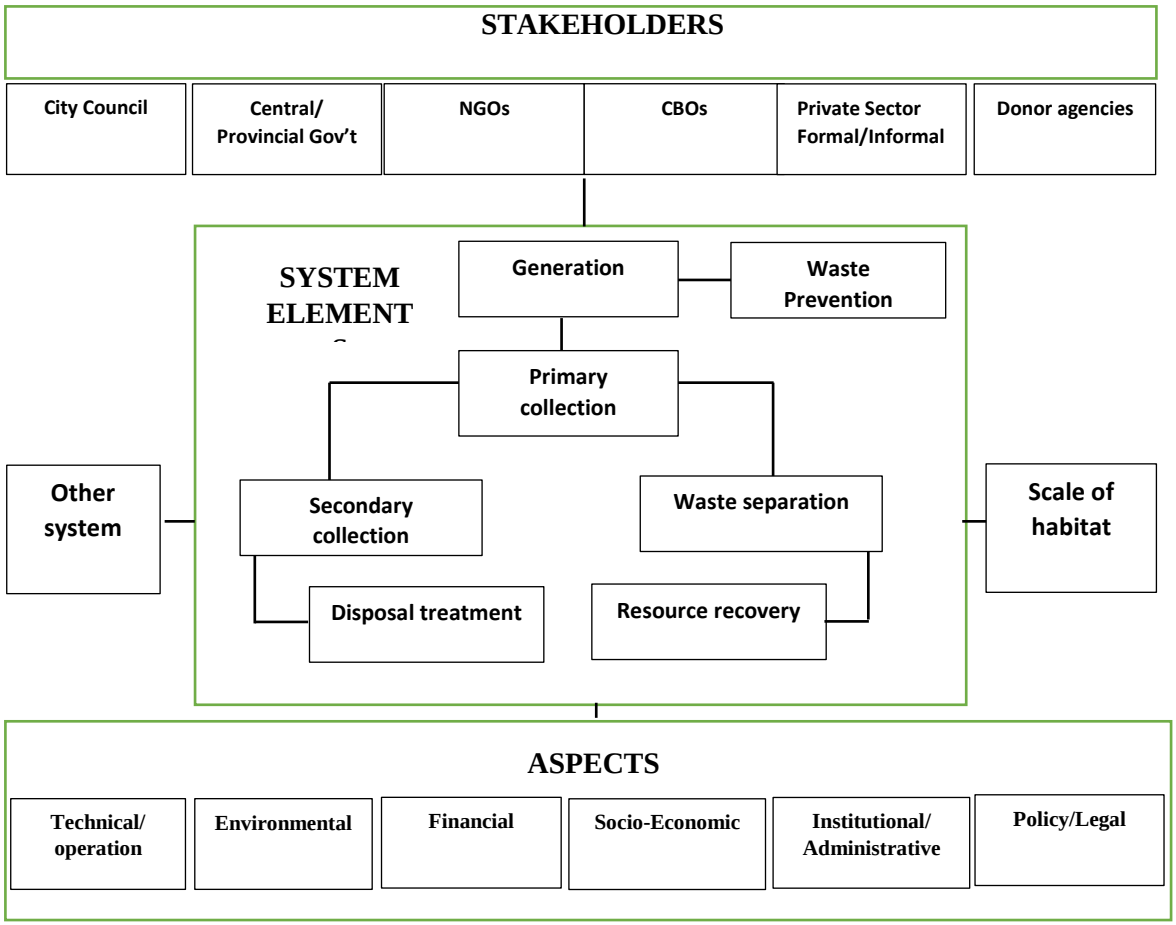
- Utilise a range of inter-related collection and treatment options used at different levels of habitats (family, neighbourhood, and city).
- Involves all stakeholders, be they governmental or non-governmental, formal or informal, profit- or non-profit orientated.
- Takes into account interactions between the waste management system and other urban systems (van de Klundert and Anschutz, 2000, p. 3).

Sustainability and integration, in a sense, are two sides of a single coin. For instance, the use of different collection and processing options at different levels of habitats may result in the formation of a system basis adapted to local conditions (physical, social, economic, etc.). Stakeholder involvement is one of the cornerstones of system sustainability, leading to a sense of responsibility for the success of the system, at least if their political and economic

interests are rendered to the system, and an ongoing readiness to sustain it as part of the stakeholders. If waste management systems are integrated with other systems, this leads to enhanced sustainability. i.e., for instance, any materials extracted from waste and used in any other application, which this can lead to a closed cycle system, thereby minimising the import of raw materials from abroad and concurrent burdens on the environment from transportation and manufacturing of chemical etc. (van de Klundert and Anschutz, 1999).

The ISWM concept is visualized in a diagram (Figure 2.4) below. The dimensions of ISWM: a range of stakeholders, different system elements, interactions with other systems and habitat scales, and six different aspects of integrated sustainable waste management that used as an assessment tool for SWM in cities of the Global South countries as shown in a schematic way (Wilson et al., 2013).

Figure 2.4 The Norm Dimensions of Integrated Sustainable Waste Management as a Tool for assessment in Global South Countries



Source: van de Klundert and Anschutz (2000, p.3).

2.3.1.1. Policy Concepts Supporting Strategic Options for Waste

Waste policies are codified at individual, institutional, industrial, national, regional and global levels. Such policies vary widely because they are driven by a huge range of causes, such as maintaining aesthetics, prestige to economic and environmental imperatives and fear of health risks such as outbreaks of disease and epidemics. The consequences of inadequate waste management, therefore, do not know national boundaries. Therefore, waste is increasingly seen as a global problem and so too solutions are needed to protect the environment in a sustainable way. From this point of view, it explains in part why global institutions, international bodies, governmental and non-governmental organisation are increasingly working together to develop a common working schedule, agreements and directive, that guide international companies, national governments and others to be involved in waste management. Some of these relevant international and regional bodies with organs of the UN, such as the United Nations Environment Programme (UNEP), UN Development Programme (UNDP) and UN Centre for Human Settlements (UNCHS-HABITAT); the World Bank; the EU, Union for the Mediterranean (UfM); and the Organisation for Economic Cooperation and Development (OECD). In spite of this, the technical and human know-how, availability or lack of funding, technologies, scavengers, and good governance remain as key determinative factors to policy options.

2.3.1.2. The Concept of Waste Recognition

Despite successful waste reduction practices, the estimated predictions continue an increase in waste quantities and complexity of composition due to continuing urbanisation and changing lifestyles that are supported by technology. At the same time, waste disposal facilities are limited, so the basic philosophy is to reduce waste with greater emphasis on prevention of waste generation (Cheremisinoff, 1995).

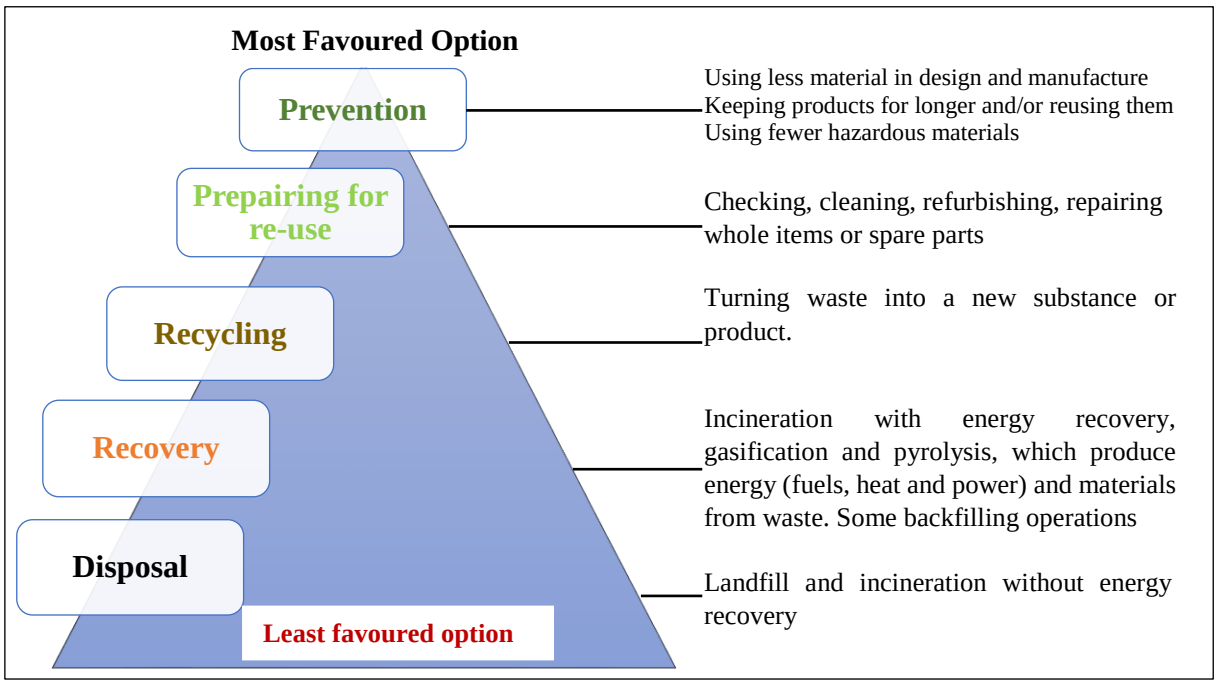
The new philosophy states that if waste cannot be prevented, it must be considered a resource through which useful things can be recovered. Waste recovery should be seen not only from an economic perspective (as in the past), but also as environmental protection for present and future generations. This concept is known as ‘Resource recognition’ (Furedy 1992). Allenby and Richards (1994, p. 69) emphasised that the post-consumption waste, industrial scrap, and unwanted by-products from manufacturing processes should not be considered waste. Instead, they are raw materials that are often significantly underused. In the same context, Gray-Donald (2001, p. 17) stated that "waste" should be regarded as an "untapped

resource". The central options for achieving these goals are from strategies that evolve from a concept called waste management hierarchy.

2.3.1.2.1. Waste Management Hierarchy

The waste management hierarchy comprises sets of approaches used for dealing with waste. The waste management hierarchy developed in the European waste policy from the EU's Waste Framework Directive of 1975 but later on, was revised into a five-step waste hierarchy for dealing with waste by the EU parliament for its waste legislation Directive 2008/98/EC. The directive presents some basic principles needed in dealing with Solid Waste Management (SWM). The five-step waste hierarchy is shown in figure 2.5, which represents the waste hierarchy as set out in the revised Waste Framework Directive, which shows the least and most sustainable option

Figure 2.5 Waste Hierarchy



Source: Adapted from (Defra, 2011; Cole et al. 2014; Šooš & Ferencz, 2015)

Waste management hierarchy is a concept that provides priority action options to waste tyre as an aspect of solid waste based on the best environmental outcome across the lifecycle of the material. As demonstrated above in figure 2.5, the priority of the options starts from top to bottom (from most to least preferred respectively), comprising prevention, preparing for reuse, recycling, recovery and disposal.

There are ongoing debates on the appropriate order of the waste hierarchy. However, its direction in terms of their order is explicit and stipulates thus: Firstly, to try to prevent waste, then endeavour to minimise, i.e. also known as source reduction (mainly by careful design via reducing the quantity of material used in the creation of products and increasing their efficiency). Next in the hierarchy, reuse is a form of waste prevention, given that the method of reuse implies the extension of the life of the product and does not involve transformative or recycling processes. While recycling is a term for recovery of the materials and then moving to the recovery stage, in order to achieve 'energy recovery' via various means. Finally, disposal can consider but has to be done safely (Fagan et al. 2001; Defra, 2011). Another source exclaims that the waste management hierarchy 'is established to identify key elements in ISWM' (Daniel & Laura, 1999, p. 18).

The waste hierarchy provides a framework for developing waste strategies for sustainable development. Accordingly, the policies in the EU have extended the horizons of waste management strategies. Such policies want strategies to step beyond the practices of safe storage and disposal and consider comprehensively, not only on the amount and volume with the character of waste arising but also on the steps that should be taken to minimise waste altogether. The new strategic approach for waste minimisation in waste management action emphasises strict avoidance or prevention. Prevention is seen as an essential key to reducing both toxicity and quantity of the waste. This approach would drive to the actual elimination of energy intensity and hazardous materials. Quantity reduction requires the use of little amounts of resources to produce the same products as reducing thickness, introducing reuse or refill systems. Re-use means using a product or components again for the same purpose i.e. more than once in its original form they were conceived (Zorpas & Lasaridi, 2013; Van Ewijk & Stegemann, 2016). However, the waste hierarchy model has come under vehement criticism and attacks. Moreover, there is compelling evidence pointing to its pitfalls. The ordering of prioritisation is seriously questioned by Van Beukering et at. (1999) and by Adams et al. (2000), who argue that the model of waste hierarchy depends merely on environmental effects, while the other aspects have been neglected. They suggest that the options of the waste hierarchy should not be ranked but rather 'used as a guide not a set of directive rules '(Adams et al., 2000) or 'considered as a menu of alternatives' (Van Beukering et al., 1999). Therefore, Van Beukering et al. (1999, p. 6) pointed out that: 'Each option on the list of waste hierarchy is equally appropriate under the right set of conditions tackling the right set of waste stream components'. Rasmussen et al. (2005) suggests they

are arguing that the hierarchy is not based on any analysis, i.e. any waste hierarchy that is fixed and immutable is therefore erroneous. A definition of ISWM by EPIC (2000) suggests that the hierarchy is too consistent to take care of spatial realities. This model also appears to put a focus particularly only on the section of waste treatment in waste management. Waste collection, which is a major problem in Global South countries, is not addressed in this model. One of the key focuses of the hierarchy is prevention by minimising toxicity and quantity at the level of production. However, many Global South countries' economies are actually consumer countries for these already produced commodities, for example tyres, and as such, prevention through reduction at the source of production does not mean much to them, nor does recycling in order to produce raw materials for industries. Therefore, maybe recycling is not useful unless there is a possibility for a local market or export market for those recycled materials.

Although the main disagreement over the principles of the waste hierarchy is centred on the base of priorities order across space, nevertheless, it is useful because it provides a range of options from which countries can make choices in order to manage wastes in an environmentally sustainable manner. Van Ewijk and Stegemann (2016) emphasise that the hierarchy is useful for illustrating how societies need to "move up" the hierarchy, rather than necessarily achieve the highest priority. In order to ensure movement up to waste hierarchy, there are various policy measures / instruments that could lead towards more sustainable waste management. These are policy measures/ instruments in support of the implementation of the waste hierarchy

2.3.2. Policy Instruments in Support of the Implementation of the Waste Hierarchy

Policy instruments are the tools that can be used to tackle waste management issues that could lead toward more sustainable waste management. A wide variety of policy instruments and measures have been developed to deal with Solid Waste Management (SWM) (Taylor, 2000). However, there is no one policy instrument or measure which, on its own, can achieve a waste reduction in a systematic way. An integrated waste management strategy requires a set of combinations of measures that need to be balanced in order to achieve waste reduction (Wilson, 1996). Unfortunately, it is not possible to present comprehensive policy instruments or even for such instruments to be classified into categories. However, there is some agreement that three broad categories of policy instruments or measures (Economic, Direct regulative and Communicative instruments) for promoting waste hierarchy can be distinguished in order to reduce waste (Turner and Opschoor 1994, p. 10).

2.3.2.1. Communicative and Information Dissemination Instruments (Public Awareness)

Waste minimization from the source requires changes in the behaviour of people, either collectively or individually, such as companies, householders and employees. Whatever policy measures are utilized, they will require support with coordinated information campaigns, both to advise people what they are required to do and to persuade them to do so (Wilson, 1996). This measure can be achieved by incentives that are intended to initiate and maintain agencies' and people's waste reduction attitudes and behaviour, which include the following:

- Dissemination of information on waste reduction policies and programmes - through education and training by simple claims (e.g. pamphlets, handbills, posters, brochures, radio and television ads) - in order to create an understanding of what needs to be done and why, and how it can be done (Vining & Ebreo, 1989; Simmons & Widmar, 1990; Katzev & Mishima, 1992; Margai, 1997).
- Convincing communication, a variant of the previous incentive, which links waste reduction to the achievement of valued goals such as personal and family security, national welfare, and the safeguard and preserves of natural resources for future generations (Bryce et al., 1997).
- Short-term incentive payments to agencies and individuals - to achieve waste minimization objectives - in the form of cash, rebates, prizes, contests, and raffles (Witmer & Geller, 1976; Jacobs & Bailey, 1982).
- Social pressure (or peer pressure) is the direct influence on people by peers, or the effect on the individual who is encouraged to follow his peers by changing their attitudes, values or behaviours to match that of the influential group or the individual. For instance, when more and more households start on a particular street in recycling, those who have not yet begun recycling become embarrassed because they do not recycle (Roales-Nieto, 1988; Wang & Katzev, 1990; Grasmick et al., 1991).
- Involvement and participation in waste minimization. Involve the agencies of the state and the national community in the development of waste minimization programs, so that those involved in the implementation of these programs at the grassroots level (i) can be provided opportunity to contribute to understanding the development of relevant waste minimization programs of local importance and (ii) a sense of duty/commitment/responsibility to participate, and thus help ensure the success of waste

reduction policies and programs that have been implemented (Folz & Hazlett, 1991; Folz, 1991)

The incentives discussed above so far could be classified either as merely exhortation, gentle encouragement (so-called small carrots) or gently persuasion (so-called small stick). Wilson (1996) expressed that the "information" can also be used as a very powerful and effective stick. This so-called community right-to-know or emissions reporting legislation (Toxic Release Inventory) that was introduced as a political expedient by the U.S in response to the Bhopal accident in India in the year 1986. This requires companies to report publicly on their emissions of chemicals in annual reports.

Generally, information dissemination and communication incentives are important in contributing to the reduction of waste. The best example that embodies of education and awareness campaigns and dissemination of information in order to comply with the legal legislation that the EU used is the zero-waste programme. One of the actions under the programme is assessing and reporting on novel approaches to tackling waste crime, which aims to demonstrate the effectiveness of new public sector-led approaches to reduce waste crime and supporting new markets for the reuse of recovered materials. One of the case studies in this programme focused on the reused and recovered waste tyre market in the UK (South East of England) in order to reduce the waste tyre crimes in the market. This programme is called Novel Approaches to Tackling Waste Crime. The programme demonstrated that one of its important elements was an education and awareness campaign, in addition to financial incentives and rewards in order to reduce the level of tyre waste in the area, that contributed to gathering information from players those have a hand in the illegal waste tyre market trade (Lawton & Briscoe, 2012).

2.3.2.2. Economic Instruments

Economists are particularly concerned about the effectiveness and relative efficiency of different policies: whether a particular policy achieves its intended objectives, and whether this policy is likely to be more effective than harmful when significant impacts occur, such as those concerning the environment, and health and safety, are taken into consideration (Anthoff & Hahn., 2010). Economic instruments have played an important role in the context of integrated waste management within Global North countries generally and in the European Community particularly. Over the past few decades, the dominant tool for achieving waste management objectives has been the use of regulations derived from environmental law (known as command and control [CAC] methods). This approach has

been responsible for much-improved waste management effectiveness with respect to waste prevention, the promotion of recycling activities and the negative environmental impacts of waste disposal. In recent years, economic instruments have received special attention as a significant instrument for the promotion and implementation of environmental legislation, while contributing at the same time to sustainable development (Hannequart, 2002).

Therefore, economic instruments can be used to deter environmentally damaging activities, improve social equity, raise revenue or recover public-sector costs (Buckley, 1991). In this regard, the economic instruments are a key promise in terms of their ability to harness market power and self-interest for sustainable development. Therefore, economic instruments have a common characteristic of providing incentives for economic agents to operate in a more environmentally sound manner. With regard to waste policy, economic instruments change the value of some element of the waste process, allowing for decisions that reflect the full social cost of the specific activity. This approach can be described as internalizing the waste process' external costs and benefits. In the category of economic instruments, different subtypes can be distinguished (Kuik et al., 1997):

- Charges and taxes, making polluting behaviour and waste generation more expensive. Charges and taxes can be imposed at different stages of the waste process that include: product charges, collection fees, disposal charges and emissions charges.
- Subsidies and other forms of financial support (such as tax cuts), making eco-friendly behaviour relatively cheap. For instance, it may reward waste recycling and/or waste prevention.
- Tradable rights/permits (to produce a definite or certain amount of waste). Rights are tradeable, which allows reductions in the polluting activity through less expensive operations.
- Deposit refund systems, also known as a deposit-return system or deposit-return scheme, where a deposit is paid to a potential waste product by the buyer, who can claim a refund after returning that product to the seller (producer), i.e. this is a surcharge on a product when purchased and a rebate when it is returned. In this way, the product retains a value, even if it becomes useless for the economic agent that purchased it, in that way preventing uncontrolled dumping. It is recognized that this method of tool applies only to a small part of the waste stream.

In general, Tojo et al. (2008) pointed out that economic instruments such as taxes, charges, or tradable permits, from a theory aspect, have many advantages compared to regulations in terms of:

1. They provide a flexible response to price signals and promote and encourage innovation.
2. They are cost-effective and encourage ameliorations to be carried out in the cheapest and most efficient way.
3. They reduce external factors so that those who pollute should bear the cost of their contamination.
4. They generate revenue that can be utilised to finance more environmental investments;
5. Finally, it may be possible to address problems that often fail by the current traditional command-and-control instruments.

By integrating marginal costs and using market forces, the economic instrument is more cost-effective than traditional instruments. These effects have already been observed in the field of environmental protection in terms that the economic instruments are more common and have more established traditions through achieving significant cost savings. For example, Carlson et al. (2000) noted that the US Environmental Protection Agency (EPA) policy to reduce sulphur dioxide emissions through using allowance trading may save between $700-800 million per year when compared to a CAC program based on a standardized emission standard. Additionally, in another study for the EPA in the US, Anderson (1999) estimated that potential savings in the use of economic instruments could amount to nearly a quarter of expenditures on the environmental pollution control.

It is clear that the use of the economic incentive approach as an environmental management instrument may have many advantages compared to command-and-control, particularly if it is used in Global South countries. In this regards, Von Moltke (2004) expressed that the use of economic incentives has great advantages because it can achieve the desired effect at the least possible cost. In particular, it is vital to those countries with limited enforcement budgets that rely only on the rules of command-and-control, as in many countries in the Global South. In the same context, Panaiotov (1994) added that economic incentive represents fewer opportunities for rent-seeking behaviour than do regulations; consequently, they are probably going to both be more effective, fair and more equitable. This is dissimilar to regulations that require enlarged administrations, budgets and extensive spending plans, while economic incentives produce incomes, which ought to be welcomed by nations confronting tight spending plans and budgetary deficiencies. One of the economic

instruments that is increasingly recognised worldly is extended producer responsibility as an efficient policy for waste management, helping to improve recycling and reduce landfilling of products and materials (OECD, 2014).

2.3.2.2.1. Extended Producer Responsibility (EPR)

The concept of EPR means that producers are responsible for their products, starting from the manufacturing stage and extending to the post-consumer stage (Fishbein, 1996; OECD, 2001). Lindhqvist (2000) defines EPR as a "strategy to reach an environmental goal of reducing the overall environmental impact of the product by making the producer of the product responsible for the entire life cycle of the product, particularly for the take-back, recycling and final disposal of the product." Beside, EPR involves a shift in responsibility for managing product waste (administratively and financially) from governments or municipalities (and thus taxpayers) to the entities that produce and market the products that are destined to become waste. This economic instrument (EPR) thus offers a financing solution for a government that would like to improve the country's waste management and recycling standards. In contrast to the traditional method of financing such activities, EPR provides a way that does not raise taxes and municipal charges. This is attractive and relevant to Global South countries and economies in transition (Lindhqvist, 2000). The concept of EPR essentially builds upon the assumption that the producer is capable to redesign products to avoid or mitigate their environmental impacts (Li & Geiser, 2005). EPR not only relocates responsibility from municipality to industry, but also motivates industry to redesign products and processes, such as utilise new materials, different designs, or innovative assembly techniques (Davis, 1999; Ferrao et al., 2006). However, the impact of EPRs on eco-design has often been limited (Lindhqvist, 2000).

In this context, EPR has been adopted in many Global South and North countries, especially in the EU countries. The legislative framework for the development of EPR at the EU level is composed both by the general legislation and specific directives framing the recovery and recycling of specific waste streams: in a Global South country such as Tunisia this has the potential to take the form of legislation for packaging waste, end-of-life vehicles, and electrical and electronic equipment waste, as well as, in reducing the disposal of the waste tyre in the landfill (Mayers, 2007). EPR could be implemented in Tunisia by a variety of policy tools such as minimum standards of recycled content; ban and restrictions on disposing of, payment of disposal fees in advance, raw material taxes, deposit/refund, and environmental labelling (Thorpe & Kruszewska., 1999). The strategy of EPR policy is

usually based on the agreements between government and waste producers, and in order to be effective, it requires certain specific conditions. In this regards, agreements are used as an "umbrella" term and refer to various "solutions" that may vary depending on the nature of the commitment, the process of setting goals, threats and incentives to encourage participation (Cunningham & Clinch., 2004). According to Holzinger (2000), assessment with agreements are generally positive, and there are opportunities to make a win-win situation to both (Government and Industries) in terms of obtaining better results together than if they had pursued individual solutions.

In contrast, Kojima et al. (2009, p. 267) argue that the EPR is difficult to implement in Global South countries in terms of smuggling the products and the identification of small-scale producers to impose responsibility upon them. With regard to imported goods, it is common for importers to be responsible for collecting and recycling at the place of original producers, but smugglers can easily evade this financial and tax liability. Manomaivibool (2009) discussed the identification problem of producers and smuggling (grey market) in Global South countries based on observations made in India. They consider that the problem of identification can controlled by strengthening customs regulation enforcement and reforming the tax structure to eliminate the grey market, where shops sell goods without a trademark and without paying taxes. Thus, the disposal of counterfeit and smuggled products is one of the most important preconditions for implementing EPR policies in Global South countries.

Another persistent challenge in middle-income and Global South countries with limited waste management systems is how to deal with the informal waste pickers that rely on these waste streams for their livelihoods. In this regards, Gupt and Sahay (2015) state the success of the implementation of the EPR scheme in Global South countries (especially those who suffer from an informal sector in the waste stream) mainly depends on a set of requirement and can be considered as a guidance manual that recommends:

- Constant monitoring of the effectiveness of the regulations;
- Setting up of the targets and monitoring of the upstream financial and physical activities.
- Imposing a penalty on the upstream producers in case they did not fulfil their obligation, this would have a trickledown effect on the downstream section.
- Each stakeholder should be able to fulfil his obligation at a relatively affordable cost.

- Support the EPR schemes by other complementary instruments ranging from regulatory frameworks to instruments influencing consumer behaviour such as landfill tax, pay-as-you-throw schemes, standards, etc.
- Integrating the informal sector into the formal sector.

In order to integrate informal recyclers/waste pickers into EPR systems where manufacturers/producers and importers bear the physical or financial responsibility of the schemes, registration, gradual integration, formalisation and professionalization of recyclers/waste pickers will be a key approach for them to fulfil necessary compliance measures. This approach is designed in order to avoid conflict and competition between informal and formal sectors (Akenji et al., 2011; Williams et al., 2013). The lack of effective inclusion of the informal sector in EPR systems can undermine the efficiency and effectiveness of EPR systems. Therefore, more efforts are needed to identify ways in which informal workers can contribute to waste management systems for the benefit of both. In this regards, OECD (2016) suggested a set of principles for those countries suffering from the informal sector to consider it when designing EPR initiatives. The following principles are:

- Recognition: The role of informal recyclers/waste pickers' play must be recognized: in low- and middle-income countries, they are responsible for the majority of the materials that are captured, processed and sold in the recycling value chain. Recognition of their role can be enhanced by compiling and documenting information about what informal recyclers are actually doing and how they are contributing to the achievement of waste management policy objectives.
- Competence: Cities in middle-income countries should think about how best to build on the expertise of waste pickers and scrap shops. They are also the only players with realistic expertise in how to optimize sustainability under local market constraints and can be provided with an incentive to easily respond to emerging supply chains and market opportunities.
- Participation: Informal recyclers/waste picker should be encouraged to contribute their knowledge, experience and skills in all applicable public decision-making processes. They should be engaged in the construction, control and assessment of recycling and recovery schemes, as well as in the definition of quality standards requirements.

- Source separation: Usually the producers and local authorities in middle-income countries often consider the separation of waste is not feasible. Therefore, these producers, authorities and recyclers must work together in order to strengthen the upstream separation for recyclable wastes on the level of businesses and households by setting down an experiment that may be organised differently, taking into consideration the local circumstances.
- Find, record, and document what works: Municipal bodies, public authorities and private producers can collaborate to gather data on waste generation and recycling rates for informal recyclers. It is important to avoid the misconception that no recycling is taking place. Seek for, evaluate and expand on current collection, processing and marketing practices, as well as active and successful small and medium-scale experiments, rather than believing that anything needs to be developed from scratch, or that existing informal processes should be replaced by (parallel) formal systems.
- Secure dignified working environments: Combine the local insights and ambitions of informal recyclers/waste pickers with global concepts of good practice to achieve acceptable environmental, health and safety working conditions for informal recyclers/waste pickers. In addition to promoting decent working conditions, occupational recognition and models of adequate and fair business.
- Business-to-business (B2B) prior to Public Private Partnership (PPP): prioritize the establishment and developing of business partnerships with informal and micro or small recycling enterprises over a PPP approach.
- Maintain inclusiveness: in the development of EPRs, involve local authorities, municipal associations, national governments, regional economic communities, to bilateral and multilateral international institutions and all related parties (e.g. producers, importers, collectors, sorters and processors). In addition to this, evaluate, disseminate, and transfer sound practices of partnership with informal recyclers into public policy and legislation; and use these partnerships and activities to boost recognition of the informal recycling sector.

2.3.2.3. Direct Regulatory Instruments or So Called ‘Command-And-Control’

Direct Regulatory Instruments (as known a, Command and Control [CAC], can be defined as “the direct regulation of an industry or activity through legislation that explicitly mentioned what is permitted and what is illegal" (Junquera & Del Brío, 2016), i.e. regulatory instruments are policy mechanisms that influence the range of alternative activities by means

of prohibition, restrictions or obligations. In this regard, the 'command' is to provide quality standards/objectives by a government authority that must be adhered to. The 'control' section refers to negative penalties that may result from non-compliance, as an example, prosecution (Abbot, 2009; Baldwin et al., 2012). CAC includes a variety of methods that influencing on behaviour through laws, contracts and agreements, incentives and threats. In the CAC, there is a perception of the problem and a control solution is developed and applied later (Holling & Meffe, 1996).

As for environmental policy and regulation, the CAC approach depends heavily on the use of standards in order to ensure improvements in environmental quality. There are three main standards that CAC approaches that can be used, which are represented in the emission standards, ambient standards, and technology standards. Indeed, in most pollution control programs, there is a set of standards that are implemented (Field & Field, 2017). Governments have used regulatory instruments since the beginning of environmental policymaking in industrialized countries in the 1970s and the CAC approach has dominated policy in industrialised countries during this decade because the general focus was on a remediation policy rather than comprehensive prevention techniques (Böcher, 2012). While many view the CAC adversely, direct regulatory control is still utilized in the environmental policy of numerous nations; for example, Germany, environmental policy has been predominantly founded on regulatory instruments for about four decades (Böcher, 2012). In this respect, CAC therefore provides a possible approach for Tunisia to adopt in the management of solid waste generally, and waste tyres in particular. Nevertheless, governments have realised that they require "better" alternatives to dominant CAC systems, which has created a major debate in both scientific and political circles since the 1980s. Accordingly, a more extensive scope of "alternative" instruments and combinations of instruments has enhanced and supplemented regulatory instruments in environmental policy regimes (Böcher and Töller, 2003).

It is possible to legislate many different types of direct, performance-based regulations to minimize MSW. Among the illustrations is an example:

(1) The ban against open burning, open dumping, littering and landfill disposal;

(2) Monitoring and controlling standards (e.g. sanitary landfill site design and construction standards; maximum emissions of waste);

(3) Compulsory participation in programmes for source-reduction (e.g. product/package return) and waste disposal program for diversion (e.g. recycling);

(4) Plans and time schedules designed to fulfil and achieve targeted minimum levels of recycling or maximum levels of packaging and mixed waste entering landfills, etc. (Taylor, 2000). In most cases, schedules for compliance, authorization and enforcement procedures, assignment of liability and penalties for non-compliance are included in such legislation. In this regards, Abbot (2009) states that to achieve the objective of command-and-control is enforcement and compliance. Therefore, direct regulation should include the highest level of compliance. This can be accomplished through appropriate implementation and enforcement. Failure to comply with the CAC regulation poses a serious challenge to its effectiveness. However, following and compliance with such regulation require considerable organisational and personal effort, or increased costs of production and operation, which some agencies or individuals may be committed to as a fundamental sense of social commitment. However, others may not be willing to follow these requirements unless they are given some new incentives, such as an economic incentive (Taylor, 2000), thus, command-and-control systems are become clearly linked to economic incentives, as described in para 2.3.2.2.

2.4. What Makes Tyres an Environmental Problem?

Since this research is about the best practice management of waste tyre disposal in a sustainable way, it is important to understand the make-up of the typical tyre. The following section highlights the unique properties of the tyre in terms of their chemical and physical composition including the patterns of tyre production and consumption. In addition, it explains what environmental problems can be caused in the case of a failure to manage tyre waste in the sustainable way? This will help to clarify why waste tyres require special attention when they are to be disposed of.

2.4.1. Properties of Tyres

The tyre is a product that has a complex structure, which can be made from different sources, either from petroleum or natural gas, such as synthetic rubbers (IIR) (e.g. mainly butyl rubber, styrene-butadiene rubber [SBR] and butadiene rubber [BR], and natural rubber [NR]), along with other components added to form the final body of the tyre (Kordoghli et al., 2014). The rubber in the tyres forms 70-80% of the component mass of the tyre, and the remainder is a mixture of Sulphur used for vulcanizing, and steel, textile and carbon black used as a reinforcement material in the tyre, as well as oil used to soften the rubber (Pehlken and Müller, 2009).

The main elements for structural components of tyres consist of a tread, belt, casing, sidewall and bead, etc., as shown in figure 2.7. It is worth mentioning that all components have an effect on the tyres average lifespan; for example, the casing of the tyre can impact on its durability and solidity, which directly affects future re-use of the post-consumption tyre, especially in the case of retreading (Tuononen, 2008; UNEP, 2013; Kordoghli et al., 2014).

Tyres generally differ from one type to another in terms of size, type, and their design according to use, and manufacturer "brand", but their composition is very similar. For example, the contents of natural rubber in truck tyres are larger than that in car tyres. In addition to this, the amount of steel wires used in truck tyres is larger than that used in car tyres, because truck tyres have to cope with heavy loads and longer distances rather than high speeds (Pehlken and Müller, 2009; Sienkiewicz et al., 2012; Kordoghli et al., 2014). Table 2.4 illustrates the content percentage of the components for tyre composition used to produce car and truck tyres and an average weight of the tyre, in both Europe and USA, highlighting some of the health and environmental effects resulting from the use of these components.

The different compositions that form tyres make their management a serious challenge in terms of the environment and technology. In the one hand, the tyres are resistant to degradation if disposed of improperly, which makes it dangerous to the environment and human health because they can become a shelter for rodents that carry diseases or in event of combustion, pollution from their components. On the other hand, tyre waste management needs sophisticated technologies to separate components that form tyres in order to recycle them into new products (Sienkiewicz et al., 2012), or technologies that perform energy recovery from waste (Lombardi et al., 2015). Broadly, a waste tyre is a valuable source of energy, which contains valuable materials that can used as raw materials for energy.

Table 2.4 Illustrates the Percentage of Raw Materials Used In Tyre and Adverse Health and Environmental Effects Based on Their Composition

Raw Materials (wt. %)[1]	In Europe[1]		In USA[1]		Based on Composition of tyres that used in the manufacturing it poses adverse health and environmental effects[2]
	Car Tyre	Truck Tyre	Car Tyre	Truck Tyre	
Natural rubber	22	30	14	27	Poses a dangerous fire hazard and when heated to decomposition emits toxic fumes of SOx
Synthetic rubber such as polymer styrene-butadiene rubber and butadiene rubber	23	15	27	14	Styrene is a suspected carcinogen to human, and many of the polymer additives can cause systemic toxic effects. For example, Inhalation of high concentrations of butadiene can cause unconsciousness and death.
Carbon black	28	20	28	28	Carbon black contain some molecules of carcinogenic materials; however, the carcinogens are apparently held tightly and are not eluted by hot or cold water, gastric juices, or blood plasma.
Steel	13	25	14-15	14-15	
Fabric, filler, accelerators, antiozonants, zinc oxide, lead oxide etc.	14	10	16-17	16-17	Zinc oxide is mildly toxic by ingestion, inhalation and skin contact. Lead oxide is moderately toxic by ingestion and is combustible by chemical reaction with reducing agents.
Average Weight	New 8.5 kg Scrap 7 kg	New 65 kg Scrap 56 kg	New 11 kg Scrap 9 kg	New 54 kg Scrap 45 kg	

Source: [1-] Sienkiewicz et al. (2012, p. 1743) ; [2-] Pennington et al. (1996).

These materials have a high Calorific[1] value equal to that of coal, where the Calorific value of the tyres is between 30 MJ/kg and 35 MJ/kg, an average of 32.5 MJ/kg, depending on the tyre type (car/ truck) (Feraldi et al., 2013; UNEP, 2013; Torretta et al., 2015). Therefore, waste tyres are excellent for providing a fuel that is useful for industries that consume a lot of energy, such as cement factories and power plants for the production of energy/steam (Sienkiewicz et al., 2012; Feraldi et al., 2013).

Accordingly, waste tyres represent both a disposal problem and a resource opportunity; for the latter, the combustion of tyre-derived fuel (TDF) could reduce the burden of the tyre stockpiles on the environment. Feraldi et al. (2013) point out that more than half of scrap tyres generated in the US are consumed in power generation for many of the cement kilns, pulp and paper mills, and other utility boilers in order to reduce the amount of conventional

[1] Calorific value or (energy value or heat value) of a substance, is the amount of heat released by a unit weight or unit volume of a substance during complete combustion, usually expressed in joules per kilogram.

fossil fuels and reduce the amount of tyre stockpiles, which take up valuable space as a result of the large physical size of the tyre, and to avoid the burning of tyres.

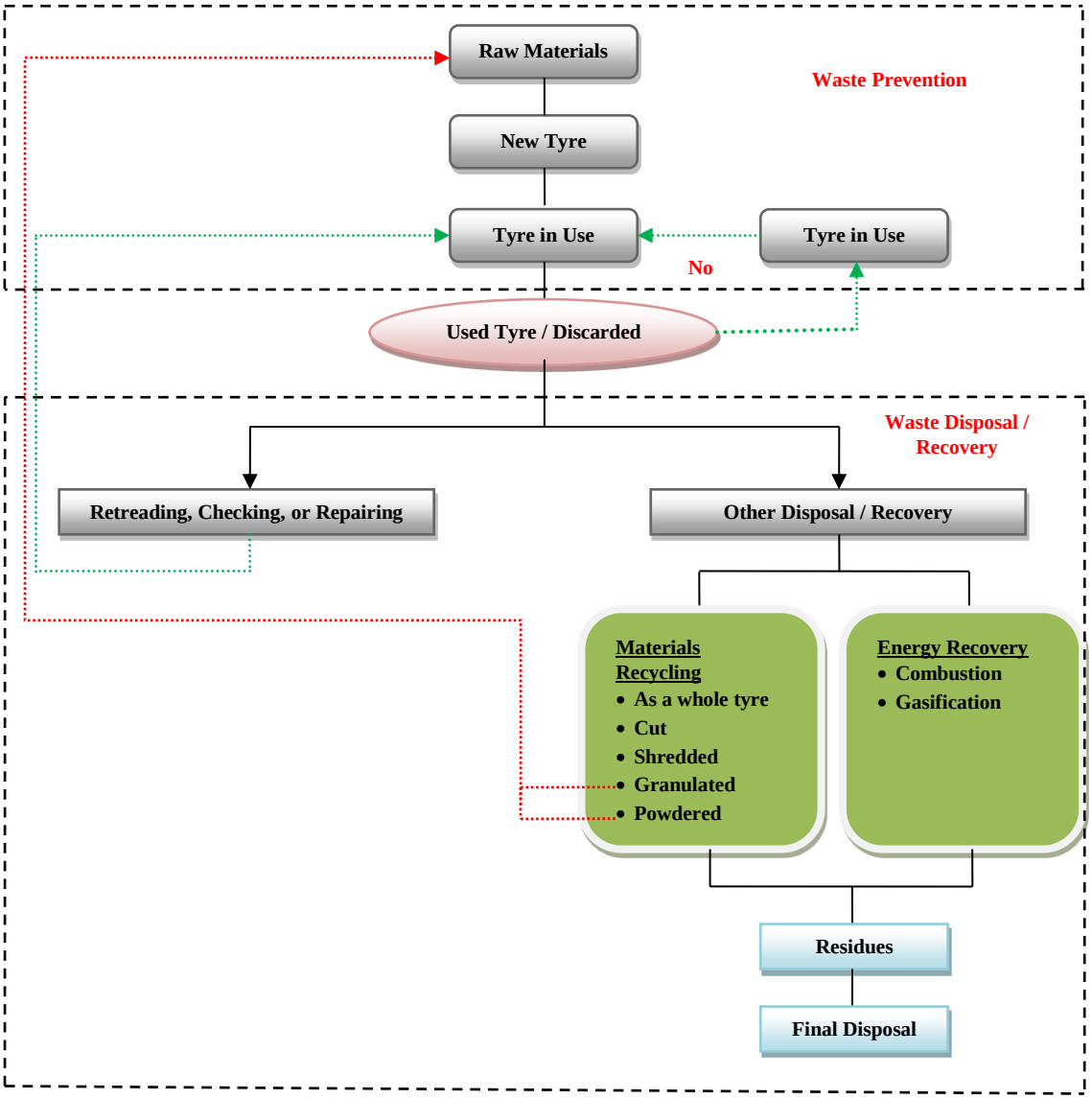
Arising out of this, the thermal treatment of waste is an inalienable part of every integrated waste management system (Porteous, 2005). For instance, the European strategy for waste management imposes that "the following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: prevention; preparing for re-use; recycling; another recovery, e.g. energy recovery; and disposal" (Directive 2008/98/EC). Reuse and recycling aim at seeking effective material recovery. For those waste flows, for which material recovery is not effectively applicable, energy recovery is the path to be followed,–taking into account also when applying the waste hierarchy, "to encourage management options that deliver the best overall environmental outcomes" (Directive 2008/98/EC).

Tyres produced that are used in the passenger car, truck and aeroplane industries are responsible for waste tyre generation in large quantities (Duangburong et al., 2015). As stated earlier, tyres generally are formed from a rubber material with a complex structure in terms of physical composition and chemical content; these characteristics give the tyres a high resistance to degradation (Sienkiewicz et al., 2012; Duangburong et al., 2015), making them prone to burning unless properly managed. Such burning poses a danger to the public health, safety and the environment (Sienkiewicz et al., 2012). Therefore, many countries in the world, such as EU member countries, have focused on the treatment and management of waste tyre generated by human activities since the declaration of the Earth Summit on Environment and Development in Rio de Janeiro, Brazil. These countries have adopted and developed the strategies, legislation, and policies that have contributed to the reduction of pollution according to the concept of the waste hierarchy.

2.4.2. The Stages of a Tyre Life Cycle

The tyre life cycle passes through several stages, as illustrated in Figure 2.6, which starts from the process of production and consumption through to the post-consumer stage. This study focuses primarily on the final stage after consumption, whilst highlighting the process of production and consumption to provide basic information that would reflect the size of the tyre produced, which is relevant to the management of waste tyres after consumption.

Figure 2.6 Life Cycle of Tyre



Source: Adapted from UNEP (2000, 2013) and van Beukering and Janssen (2001).

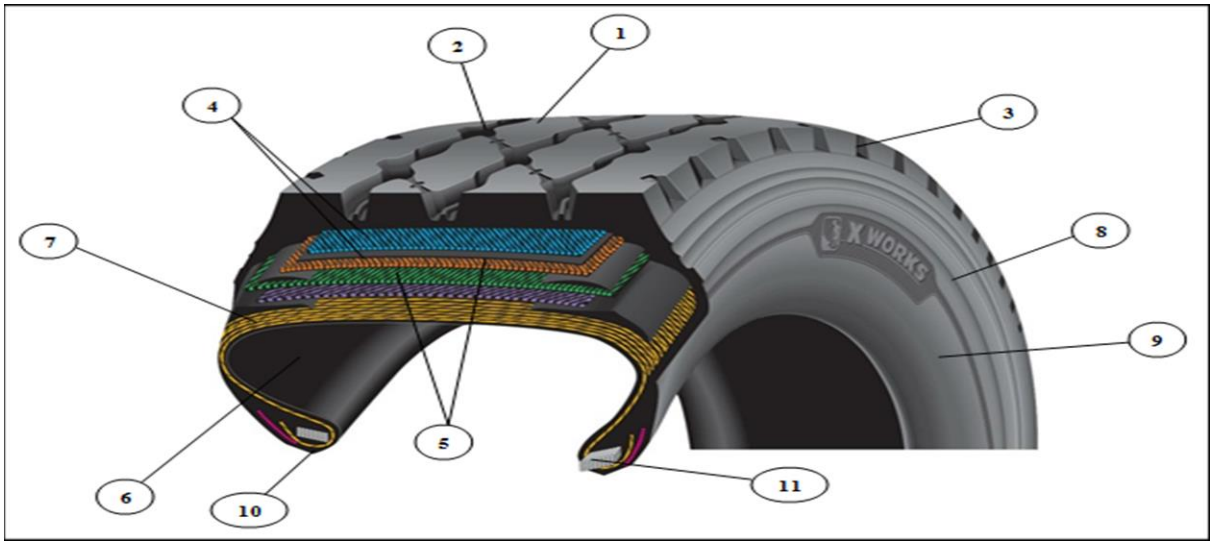
2.4.3. Production

The demand for automobiles has increased, accompanied by an increase in the production scale of the tyre industry. The largest associations of tyres and rubber products have stated in their annual reports that the global production of tyres is about 1.4 billion units (WBCSD, 2010; Japan Automobile Tyre Man Association [JATMA], (2011); ETRMA, 2011).

The tyres are made of several components, of which the most important include various rubber compounds, textiles, iron and chemical additives for tyre production, a process which is intensive and requires a great deal of material and energy (Kordoghli et al., 2014). Rubber compounds include natural and synthetic rubber. Natural rubber comes from the biomass collected from Hevea brasiliensis "*rubber tree plant*", while synthetic rubber is obtained from sources of oil and coal, requiring several steps for production (Sienkiewicz et al., 2012; Martı´nez et al., 2013).

Tyre manufacturing is a complex technology, where all input material in the tyres contribute to certain properties of the tyre through the vulcanization process to create bonds between molecules. Vulcanization gives tyres their unique characteristics for use, and this is what makes the tyre processing post-consumption a difficult task, requiring a great deal of time and energy (Sienkiewicz et al., 2012; Martı´nez et al., 2013; Kordoghli et al., 2014). Figure 2.7 shows the major components of parts that make up the tyre with definitions of technical terms, which are terms expressed by UNEP (2013) with the intention of clarifying and acknowledging these ingredients to give general information to those involved in the operations to manage used and waste tyres according to international standards and regulations.

Figure 2.7 Main Components of the Tyre



- “Tread” (1) means the outer part of the tyre designed to contact with the ground surface;
- “Tread groove” (2) means the space between the adjacent ribs present in the top surface of the "tread" pattern;
- “Sidewall” (3) means the part of a tyre set between the tread and the area designed to be covered by the rim flange;
- “Ply” (4, 5) means rubber layer coated in parallel to cords in the radial tyre, which gives stability to the tyre;
- “Cord” (6) means the strands forming the fabric of the plies in the tyre;
- “Carcass” (7) means the structural part of the tyre, other than the tread and outermost rubber of the sidewalls, which when inflated supports the load;
- “Section width” (8) means the linear distance between the outside of the sidewalls of an inflated tyre, when fitted to the specified measuring rim, but excluding elevations due to labelling (marking), decoration or protective bands or ribs;
- “Belt” (9) refers to a radial ply or bias-belted tyre; it means a layer or layers of material or materials underneath the tread, laid substantially in the direction of the centre line of the tread to restrict the carcass in a circumferential direction;
- “Bead” (10) means the part of a pneumatic tyre that is shaped and structured to fit the rim and hold the tyre on to it;
- “Chafer” (11) means material in the bead area to protect the carcass against chafing or abrasion by the wheel rim.

Source: Adapted from UNEP (2013, pp. 6-7)

2.4.4. Consumption and Post-Consumption Stage for Tyres

Intended consumption is the period between when the new tyres are fitted to the vehicle and go on the road until the end of their life, and this consumption depends on two factors: the expected tyre lifespan and driving behaviour (van Beukering & Janssen, 2001). Addressing these factors remains one of the priorities of the waste hierarchy, whilst top priority goes to preventing waste in the first place, i.e. using less material in design and manufacture by keeping products for longer (Anne and Russ, 2006). In this regard, the expected lifespan of the tyre has improved during the past 40 years with the development of industries, doubling the mileage of tyres (Van Beukering and Janssen, 2001). On the other hand, to reduce tyre consumption, driving behaviour should be maintained in terms of not neglecting the air pressure of tyres, observance of speed limits and avoiding abrupt braking (Holmberg et al., 2012; Abdullah et al., 2013).

Car tyres are generally designed to cover a distance of approximately 65,000 kilometres, and this can increase to 95 000 to 128 000 kilometres if tyres are properly inflated and cared for (van Beukering & Janssen, 2001). In Europe, the car tyre replacement is estimated to be between 3.5 years or 30,000 km and 6 years and 80,000 km, depending on the mechanical load (Pehlken & Müller, 2009). As a result of lack of care, most of the dissipated material occurs on the tread part that is made from rubber only (van Beukering & Janssen, 2001) and it is estimated that a tyre loses 10% of its weight as a result of not following the guidance of the maintenance booklet. As people do not follow the guidance, there is therefore uncertainty surrounding the dates of when a tyre will become scrap and all figures given here are only estimations. Nkosi et al. (2013) support this notion, indicating that avoidance of consumption of tyres and prolonging their life span depends on consumer awareness and their ability to follow the guidelines and procedures for regular maintenance as recommended by the producer. This kind of maintenance keeps the tyre in good condition with the intention of extending the lifespan of the tyres. Thereafter, the tyre enters its post-consumption stage. The post-consumption stage commences when a tyre is replaced by a new tyre or when a vehicle is scrapped. The post-consumer stage of the tyres poses an issue in the environment, especially when disposing of it without recovery or recycling. The post-consumption of tyres, on the one hand, is either due to it becoming a 'partly worn' tyre, i.e. may be reused or retreaded. On the other hand, the tyre becomes worn out, i.e. has reached the end of life (as waste) and therefore cannot be reused for the same original purpose but can be used as raw material or for energy production (Limbachiya & Roberts, 2004; Nkosi et al., 2013).

2.5. Overview of Waste Tyre Problems

Waste tyre generation considered one of the most significant environmental issues because of the fire hazards tyres represent and the environmental and public health risks as a result of their chemical and physical components if not managed properly (Martı´nez et al., 2013). The discarding of waste tyres in Europe increased from 2.1 million tons in 1994 to 3.3 million tons in 2010 (Sienkiewicz et al., 2012). Illegal discarding of waste tyres may occur due to a lack of specific regulations and/ or because recycling is not economically attractive (Martı´nez et al., 2013), a practice that is prevalent in Global South countries such as Tunisia. Consequently, disposal of waste tyres is considered an increasing economic and environmental burden that needs an immediate solution (Martı´nez et al., 2013). From an environmental point of view, waste tyres are considered a place for rodents, snakes and mosquitoes to inhabit, and additionally, tyres take up a lot of land space (Sienkiewicz et al, 2012; Martı´nez et al., 2013). Table 2.5 illustrates some negative environmental hazards relating to the mismanagement of waste tyres.

2.5.1. Human Health Problems

Disease-carrying mosquitoes are the most important public health risks worldwide. Dengue fever infection is one of the most important arbovirus diseases in humans, causing sudden fever and acute pains, threatening more than 2.5 billion people. It is endemic in many regions of the world such as Africa, the Americas, eastern Mediterranean, SE Asia, and the Western Pacific (Reschner, 2008; Getachew et al., 2015). Waste tyres are a convenient place for the growth and breeding of mosquitoes, which have the ability to multiply and spread all over the world, and the movement of used tyres between countries contributes to the introduction of non-native species such as mosquitoes. For example, the Asian tiger mosquito recorded a European presence for the first time in Albania in 1997 due to the international trade of used tyres, and since then its presence has been reported in more than one European country. *Stegomyia albopicta* is considered the most significant mosquito species in terms of their capacity to spread infectious viral diseases (Pluskota et al., 2008).

UNEP (2013) has stated that waste tyres, if not managed properly, will cause a risk to public health, because they are the ideal place for mosquitoes that transmit dengue fever and yellow fever, especially true for the tropics and subtropical regions. Thus, the movement of the tyre through international trading of used tyres can contribute to the introduction of non-native species of mosquitoes to new countries, which is then often difficult to control and increases the risk of disease**.**

2.5.2. Fire Hazards

Tyres are also considered a raw material for chemical materials, as a construction material, and as a type of solid fuel because they contain a high density of energy at 29-37 MJ kg. However, the chemical materials present in tyres such as carbon, sulphur, rubber, oil, and benzene are flammable materials. Thus, tyre storage and reuse requires care and attention to avoid fire risks, because the burning of tyres pollutes the soil and ground water (Martı´nez et al., 2013; Downard et al., 2015). In addition, burning can generate gaseous emissions such as sulphur oxides (SO2), carbon monoxide, and polynuclear aromatic hydrocarbons (PAHs), all of which pose significant risks to human health in the event of exposure through inhalation.

Table 2.5 Level of Environmental Problems

Environmental impact	**Illustration**
Soil & Water contaminations The burning of tyres can easily contaminate the soil and water as well as causing loss of vegetation and the ecosystem as a result of soil erosion due to lack of vegetation in the area. This photo cited by the Virginia Department of Environmental Quality illustrates the event of burning tyres in Frederick County near Winchester in 1983, which continued for nine months (VDEQ, 2016)	  Source: VDEQ, 2016. Waste Tyre Pile Cleanups. www.deq.virginia.gov.
Earth pollution & health hazards Illegal disposal of waste tyres is leading to an accumulation of waste and encourages the development of illegal dumpsites, which create a mixed waste, causing distortion of the aesthetic view of the natural environment, and creating a convenient haven for rodents, insects and mosquitoes.	 Illegally dumping waste tyres in the residential area in Tunisia leads to creating illegal dumpsite sites mixed with other waste. **Photo has taken by the author.**   **Photo taken by the author.** Waste tyres take a long time to degrade and as a result, they will remain in the illegal dumpsite for a long time, causing various impacts on the environment.

Sources: The author; VDEQ (2016)

Moreover, uncontrolled tyres may cause a fire that is difficult to extinguish, causing widespread damage. In spite of warnings and legislation urging caution towards fire hazards from waste tyres there are still many accidents occurring. For example, the largest tyre fire happened in 1983 in Virginia, United States, where about 7 million waste tyres burned and

the fire continued for nine months, which caused pollution of the local air and water (Virginia Department of Environmental Quality [VDEQ], 2016). As another example, Iowa City in the United States witnessed a fire lasting for 18 days in 2012, because of an accidentally igniting shredded tyre commonly used as a lining material in landfill drainage. Singh et al. (2015, p. 196) ironically explained that, "this practice is considered as a method for disposal of scrap tyres" and was meant to be an innovative use for the material; however, improper monitoring resulted in the burning incident. The one million shredded tyres generated smoke that affected the surrounding area, which was inhabited by more than 130,000 people. The public health damage in that area was of serious concern, which demonstrates the need to be wary of this form of waste (Singh et al., 2015).

Although European laws have banned the full storage of tyres, according to the directive 2003/35/EC and Directive 2006/12/EC of the European Parliament and the Council on waste, fire incidents persist.

Recently, on Friday 13 May 2016, the Independent newspaper reported that a fire broke out at a tyre graveyard near Madrid. This disaster caused the evacuation of more than 9,000 people from a large housing complex because of the escalation of the toxic black clouds sent out by the raging fire, as shown in Figure 2.8 (Clendenning & Giles, 2016). UNEP (2013) has explained that tyre fires in the open air omit black smoke, carbon dioxide (contributing to the greenhouse effect), volatile organic compounds and hazardous pollutants, such as polycyclic aromatic hydrocarbons, dioxins, furans, hydrochloric acid, benzene, polychlorinated biphenyls, arsenic, cadmium, nickel, zinc, mercury, chromium and vanadium.

Figure 2.8 Fire from Burning Tyres with Thick Smoke Pouring Out

Source: Clendenning and Giles (2016).

Finally, it can be concluded, as presented above, that the composition of the tyres predetermines the properties of the tyres and their effect on the environment. At the end of their life cycle, tyres are of great environmental concern, especially when disposed of with traditional methods such as a landfill. The disposing of waste tyre at the landfill is not only an environmental and public health hazard but also a waste of valuable materials and energy. After taking a closer look at the chemical and physical tyre composition with their production and consumption patterns, positive trends of prolonged tyre life span and tyre manufacturers' involvement in the whole life cycle can be observed. This evolution may have a positive impact on tyre processing after their consumption, which may ultimately bring benefits to the environment.

2.6. Progress and Trends in Solid Waste Policies and Strategies in EU Countries

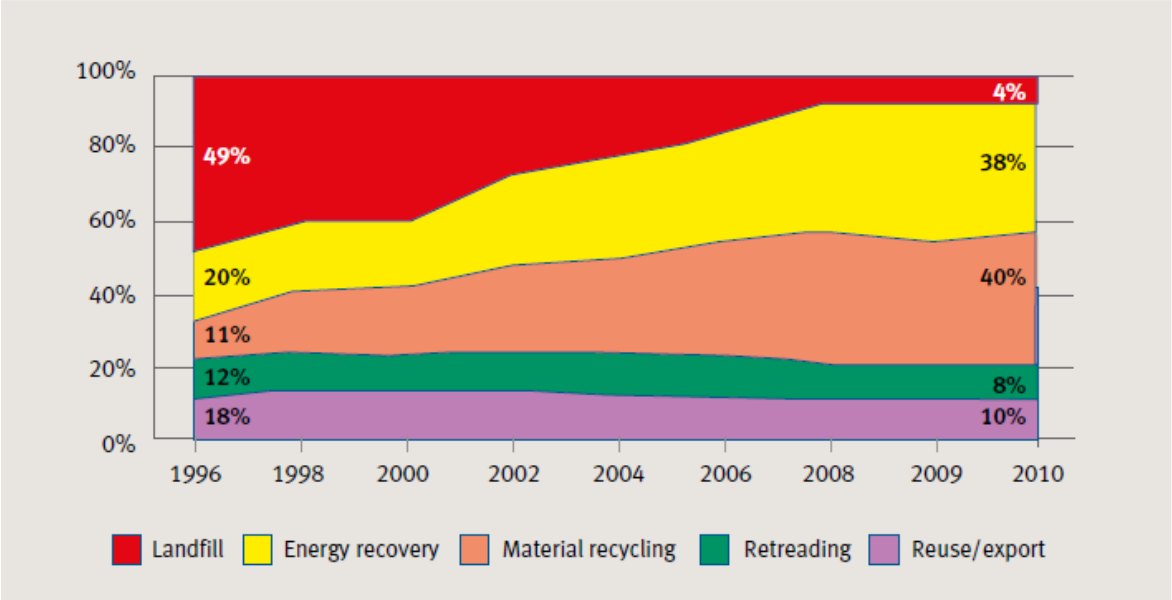
The European Commission presented Directive 2008/98/EC on waste (Waste Framework Directive), which defines the basic concepts and definitions related to waste management, such as definitions of waste, recycling, and recovery. The EU strategy on waste and sustainable use of natural resources aims to deal with waste without creating a negative impact on the environment and public health (Chen & Chen 2013). Therefore, the legislation and policy adopted by the EU counties concerning solid waste and waste tyres management have led to solutions that have enabled such a large stream of solid waste and waste tyres to

be converted into energy or to new materials, in accordance with the concept of the waste hierarchy (Sienkiewicz et al., 2012). In this regard, to a large extent the EU has achieved a transition to sustainable practices of Solid Waste Management (SWM) systems and waste tyre management.

EU countries have post-industrial economies, which are characterised as politically stable, and have a high level of human development, including high income per capita (World Bank, 2008; Klugman, 2010). Over the last 40 years, a transition has occurred in the EU towards sustainability in waste management, since the first Waste Framework Directive in 1975. In this regard, the EU has included waste policy provisions for improving the environmental impacts of waste through stringent procedures, as well as setting a conscious goal for the use of waste as a resource (Pires et al., 2011). The EU policy and strategy of waste has been developed in accordance with the Waste Framework Directive issued in 1975 to establish integrated SWM systems as part of the broader plan for the EU's policy for sustainable development. For example, the EU adopted a sustainable development strategy immediately after Agenda 21 was published, which aims to continuously improve quality of life for our present and future generations (Hawkins & Shaw, 2004; Pires et al., 2011).

Waste policy at EU level focuses on adopting the waste hierarchy by promoting reuse and recycling while enhancing waste prevention (CEC, 2005). Meanwhile, the EU promotes a transition to sustainable waste management by establishing legislation on the procedures relating to the use of automobile tyres. Since 2000, European countries' waste tyre disposal to landfill have been prohibited under European Directive 1999/31/EC; in this context, the member states in the EU have a right to identify their own national initiative to reach the required EU targets (Sienkiewicz, 2012). Figure 2.9 illustrates the outcomes of the SWM strategies' success in the EU, in particular for tyre waste between the years 1996-2010. In this regard, there were more than 24 million tonnes of used tyres managed in an environmentally sound manner, which resulted in the year 2010 in disposing only of 4% of waste tyres produced into landfill, against 96% put to other purposes (38% energy recovery, 40% material recycling, 8% re-treading, and 10% re-use /export) (ETRMA, 2011). In general, SWM strategies have transformed into an effective model that achieved their objectives in the reduction of waste disposal to landfill through increases of the recycling rate (Skovgaard et al., 2008).

Figure 2.9 Evolution of the Management of Waste Tyre Recovery in Europe



Source: ETRMA (2011)

Environmental impacts of waste are highly dependent on its size, characteristics, and how it is managed (Michaud et al., 2010). Effective waste management in terms of recycling or energy recovery can contribute to the reduction of the volume of waste consigned to landfill. This leads to reducing the proportion of greenhouse gas emissions to "negative", and therefore, this could partially offset the emissions that occur with the extraction of raw materials or during manufacturing products, which contributes to meeting the [2]Kyoto targets (Skovgaard et al., 2008). For instance, Life-Cycle Analysis (LCA) has demonstrated that recycling innovations and technologies have comprehensive environmental benefits for many types of waste (Michaud et al., 2010). Therefore, there is a need for a regulatory approach that ensures regulations on paper that can be implemented effectively in practice (Van de Klundert & Anschutz, 1999). In this way, it is important to highlight the set of Legislation Directives that the EU has drafted (see figure 2.10) that will promote sustainable waste management through enhancing internal institutional structures that will aid the arrangements, financial schemes and mechanisms, technology selection and adoption and involvement of stakeholders (Pires et al., 2011).

[2] The Kyoto Protocol is a formally concluded and ratified agreement between countries, an 'international treaty', which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits State Parties to reduce greenhouse gas emissions, based on the premise that (a) global warming exists and (b) human-made CO2 emissions have caused it.

2.6.1. EU Legislation Directives

Within the European context, the EU Legislation Directive is the master driver for developments in waste management policy (including waste tyre management) in the individual Member States. In spite of the fact that there is no direct EU regulation targeted more specifically at waste tyres, a number of Directives manage it indirectly (see Figure 2.10) linked to their management (Ferrão et al., 2008; Costa et al., 2010; Fischer, 2011; Sienkiewicz et al., 2012).

The key legislative framework in the EU is represented in the following Legislation Directives:

- Framework Directive on Waste/ Directive 75/442/EEC

This is the most important EU Directive that establishes the general principles of waste management. This Directive set out controls for waste to prevent or reduce waste production and its harmful effects. The above Directive has been reviewed and replaced with a new one to clarify definitions, objectives and the relative status of different waste management approaches. The updated Framework Directive on Waste/WFD, 2008/98/EC replaces Directive 75/442/EEC. This Directive is to ensure sustainable waste management in practice, including a revision of the waste hierarchy.

- Landfill Directive/ Directive 99/31/EC, OJ L 182, 16.7.1999

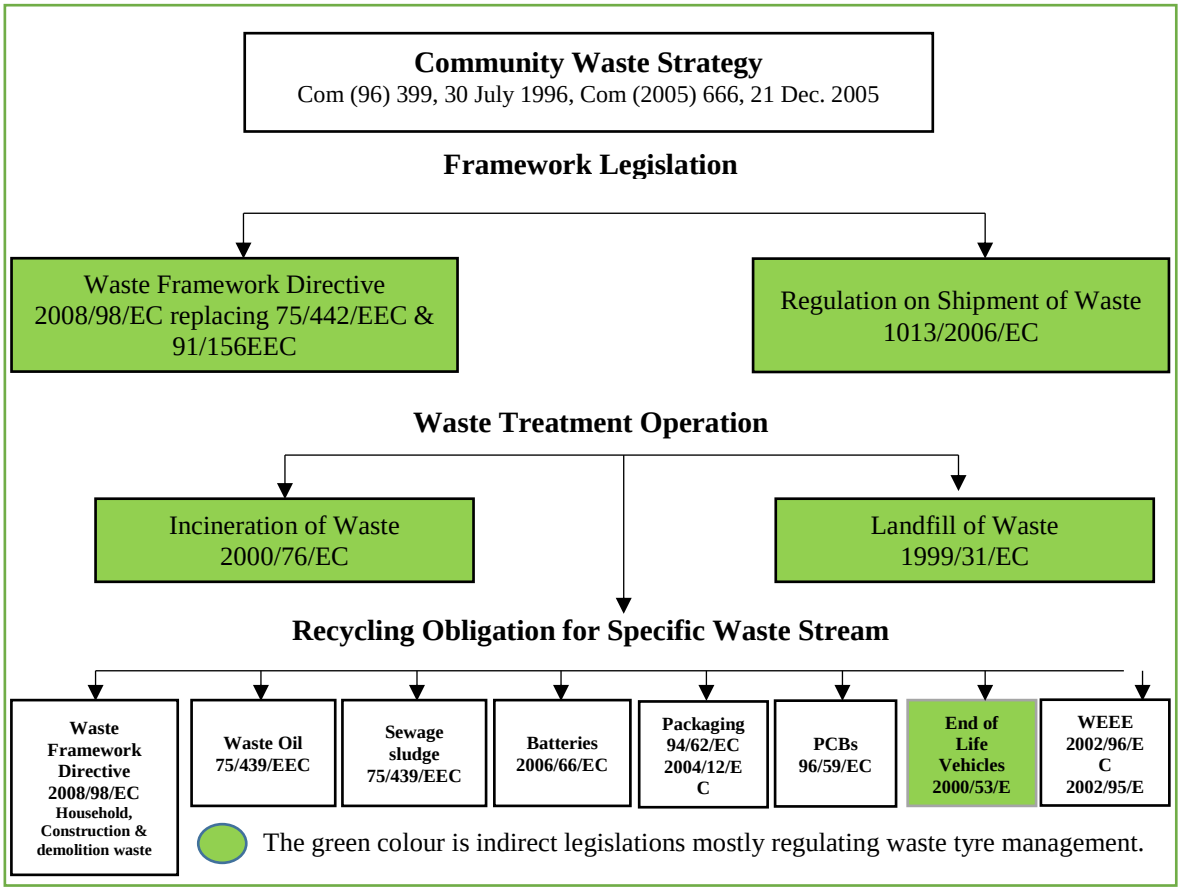
This Directive is a dominant key instrument for the waste tyre sector in the EU. The Directive requires all EU member states to ban the disposal of whole tyres in landfills from July 2003 and shredded tyres from July 2006. One consequence of this ban is to stimulate the evolution of alternative remediation options and increase the recycling rate of waste tyres. Beside this, the same Directive gives an exemption applicable to bicycle tyres and tyres with an outside diameter above 1.4 metres. In addition, there is an exemption in that utilising waste tyres at landfills for engineering purposes is permitted, but only provided the tyres are incorporated into an appropriate engineering structure and as an alternative to primary materials.

- End-of-life vehicles (ELV) Directive/ Directive 2000/53/EC, OJ l 269, 21.10.2000

This Directive requested the EU member states to ensure that a minimum of 85%, by weight, of vehicles are reused or recovered (including energy recovery) of which at least 80% must be reused or recycled from 2006, increasing to 95% reused or recovered (including energy recovery) and 85% reused or recycled by 2015. In this regard, the tyres account for around 3.5% of the weight of an average ELV (Zorpas and Inglezakis, 2012).

- Waste Incineration Directive/ Directive 2000/76/EC has been substituted by "Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control) based on the application of the best available techniques (BAT). This Directive has more stringent emission standards applied to cement kilns, where waste tyres are made into a secondary fuel. As a result, old wet cement kilns that cannot meet the lower emission standards may have to close or no longer accept tyres as a secondary fuel.

Figure 2.10 Main Legislation Directives in the EU



Source: Adapted from Fischer (2011)

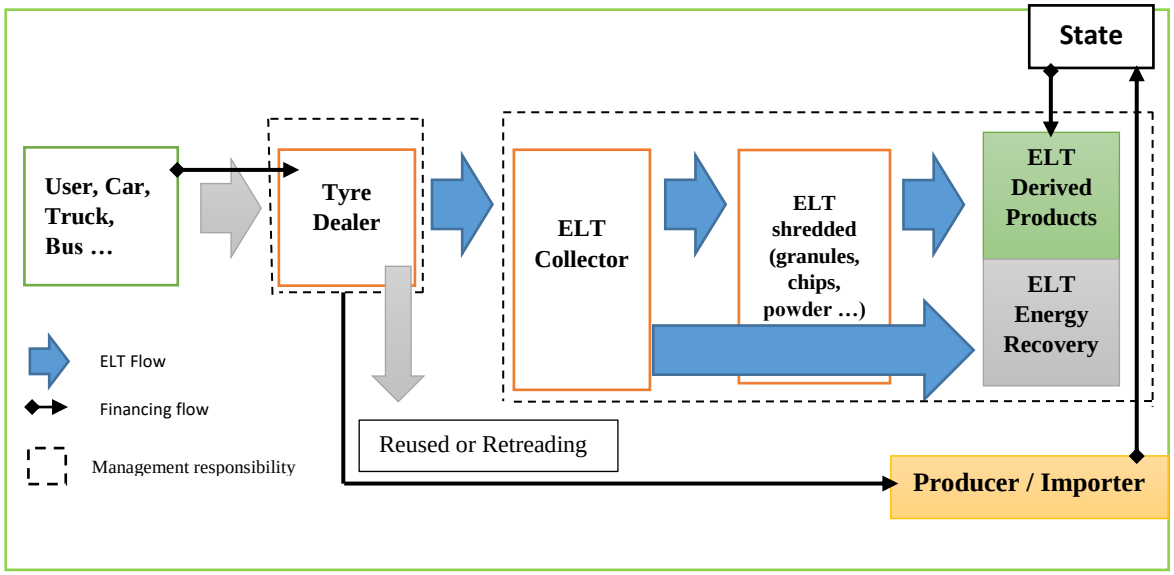
According to the above, the EU Member States have to be in compliance with the EU legislation in transposing the Directives into local legislation. They are free to set national initiatives to reach the EU targets. In regard to the development of waste management policies at the national level, the Landfill of Waste Directive has been a major driver for setting ELT management systems in Europe. Today within the EU there are three different systems for managing the ELTs that clarify the producers' responsibility, tax system (Government responsibility) and the free-market system.

2.6.2. Systems for managing the End -of- Life Tyres (ELTs)

2.6.2.1. Tax System (Government Responsibility)

The tax system is a model for the management of waste tyres, which is used globally and by EU countries such as Denmark and the Slovak Republic. These countries have adopted a taxation system (see Figure 2.11) to assist in the recovery/ recycling of end of life tyres, financed by a levy on tyre production paid by the producer or sellers, which in turn is passed on to the customer. In other words, the tax or levy is utilised in the organisation of the waste tyre collection system and rewards the operators in the waste tyre recovery chain (ETRMA, 2011; Sienkiewicz et al., 2012).

Figure 2.11 Tax System Process



Source: Adapted from ETRMA (2011); WRAP (2008).

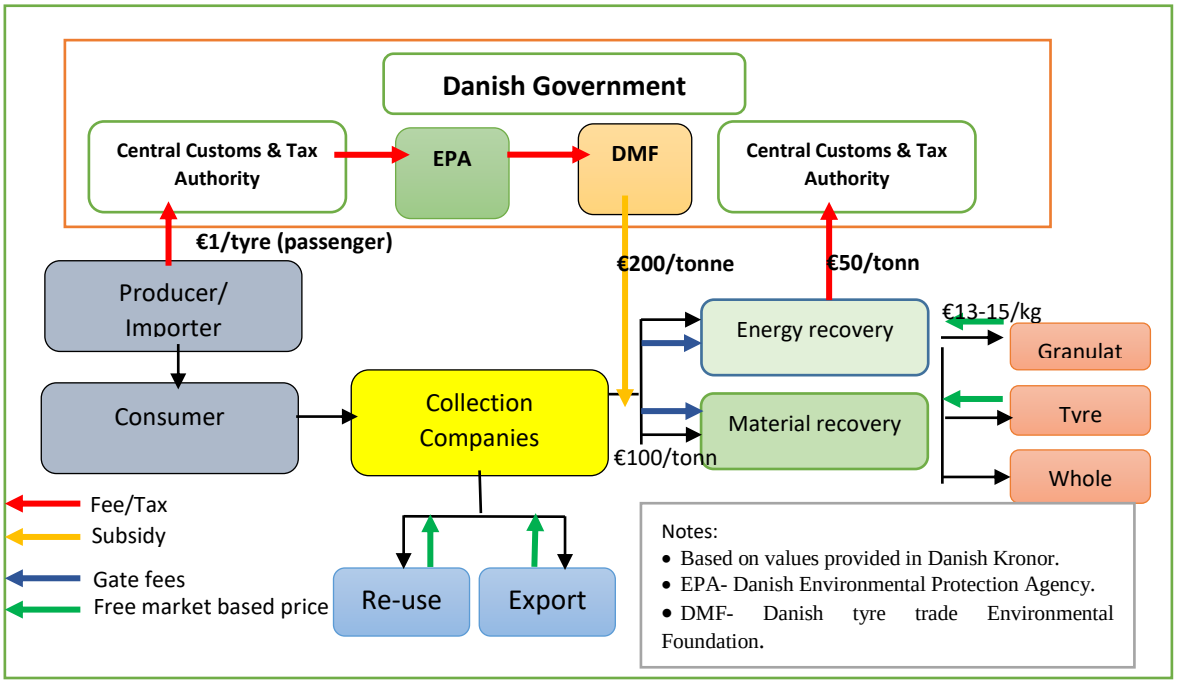
2.6.2.1.1. The mechanism tax system in Denmark as a case study

Denmark has succeeded in achieving one of the world's highest rates of waste tyre recovery (see table 2.6) through combining the tax system with regulatory instruments.

The main driver of the regulatory framework related to waste management is the Danish Environmental Protection Law (Art. 53), which provides that importers and producers of products (including tyres) are requested to pay a tax that covers either full or partial costs related with end-of-life disposal and management of these products (Hjelmar, 1996). In 1995, the first Danish Statutory Order was introduced and it was amended in 2000 with economic incentives regarding scrap tyres in order to collect and recycle waste tyres in an environmentally sustainable way. Accordingly, the Danish Ministry of the Environment and municipal authorities signed an agreement with the Danish Association of Motor Vehicle

Trade and the Danish recycling industries for a take-back scheme on waste tyres. The target of this agreement was to avoid landfilling and to ensure that waste tyres are collected, recycled or combusted, taking into consideration that the material recovery has a priority over energy recovery (Smink, 2007; WRAP, 2008). Figure 2.12 below represents diagrammatically the payment schemes set out in the Statutory Order, illustrating the flow of finance within the overall waste tyre management framework.

Figure 2.12 Waste Tyres Management Framework in Denmark



Source: Adapted from WRAP (2008)

- **Flow and Waste Tyre Disposing**

Most waste tyre disposal sources come from retailers, private consumers, industrial and commercial customers. In this regard, certified collection companies collect the waste tyres from retailers; for example, garages for repair services, vehicle dismantlers and municipal collection schemes. Besides this, the company separates tyres that are still suitable for retreating or reuse (this kind of tyre is not eligible for government subsidies). Thus, these suitable or eligible tyres are delivered to the facilitator for re-use or recovery. When the collection company delivers these suitable tyres to the recovery facility it receives a subsidy for each tyre delivered, but the collection company has to pay a gate fee to the receiving facility. The fees gate is determined by market forces. As combusting waste tyres for energy recoveries is less common, this is only an option in Denmark for non-passenger vehicle tyres,

under the law. There is a tax of €50 for each tonne of waste tyres that are combusted or put into landfill, which makes them economically unattractive for combustion or landfill.

- **Roles and responsibilities**

- Producers - Producers are responsible financially for the waste tyre disposal they place on the Danish market in terms of collection and treatment by paying the fees to the Danish Environmental Protection Agency (EPA) via the Central Customs and Tax Authority.
- Public Authorities – Representatives in Ministry of the Environment with Municipalities are responsible for waste tyre collection. The Danish EPA certifies waste tyre collection and treatment facilities and settles disputes between the scheme administrator and collection and treatment facilities.
- Scheme Administration- This scheme has been administered by the Danish Tyre Trade Environmental Foundation (DMF), which was approved by the Ministry of the Environment and the Danish EPA.
- Tax - The fee amount to be paid by the producers is determined according to categories of the tyres in terms of type and size of a tyre, which was established in part 1 of the "Statutory Order related to tyres and recovery subsidy, which ranged between 0 to 23.40 Euros per unit (WRAP, 2008; Alliance, 2002).

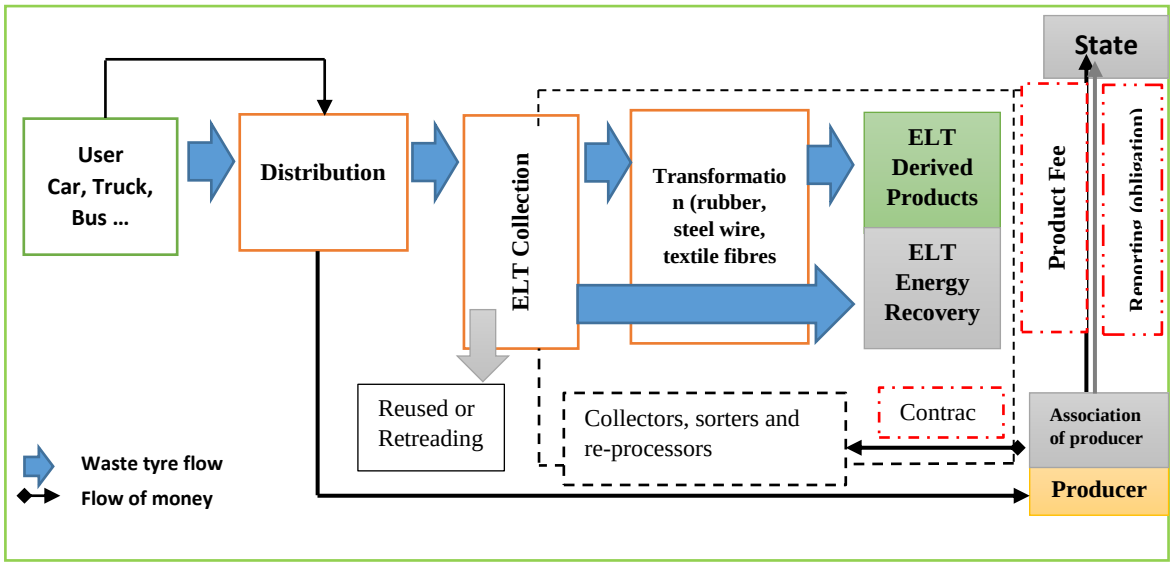
2.6.2.2. Producer Responsibility (PR)

The concept of Producer Responsibility (PR) (as mandatory) means that the producers are responsible for their products that start from the manufacturing stage and extend to the post-consumer stage (Fishbein, 1996). Some European countries at the present time have taken a step in the process of transition to the producer responsibility system, such as France, Italy, Spain, Belgium, Czech Rep and Estonia, as shown in Table 2.6 (ETRAM, 2011). In this context, the management of waste tyres is the producer's responsibility (manufacturers and importers), which obliges producers to organise the collection of used tyres for recycling and recovery according to the legally required levels of the waste (ETRAM, 2011; Karagiannidis and Kasampalis, 2010). In this regard, Karagiannidis and Kasampalis (2010) state that this system seems to be appropriate and robust in dealing and settling the ELT generations in a sustainable manner for the future, and in some countries, it has achieved 100% recovery rate.

The mechanism of this system (see Figure 2.13) is that typically, tyre manufacturers set up a producer responsibility organisation (normally as a not-for-profit company) responsible

for waste tyre collection and recovery. The cost of this system is paid by the members of the organisation as a fee per unit/tyre (the fee varies between countries); the cost is eventually covered by a charge paid by the consumer when buying a new tyre (this fee is often indicated on the price tag) (WRAP, 2008).

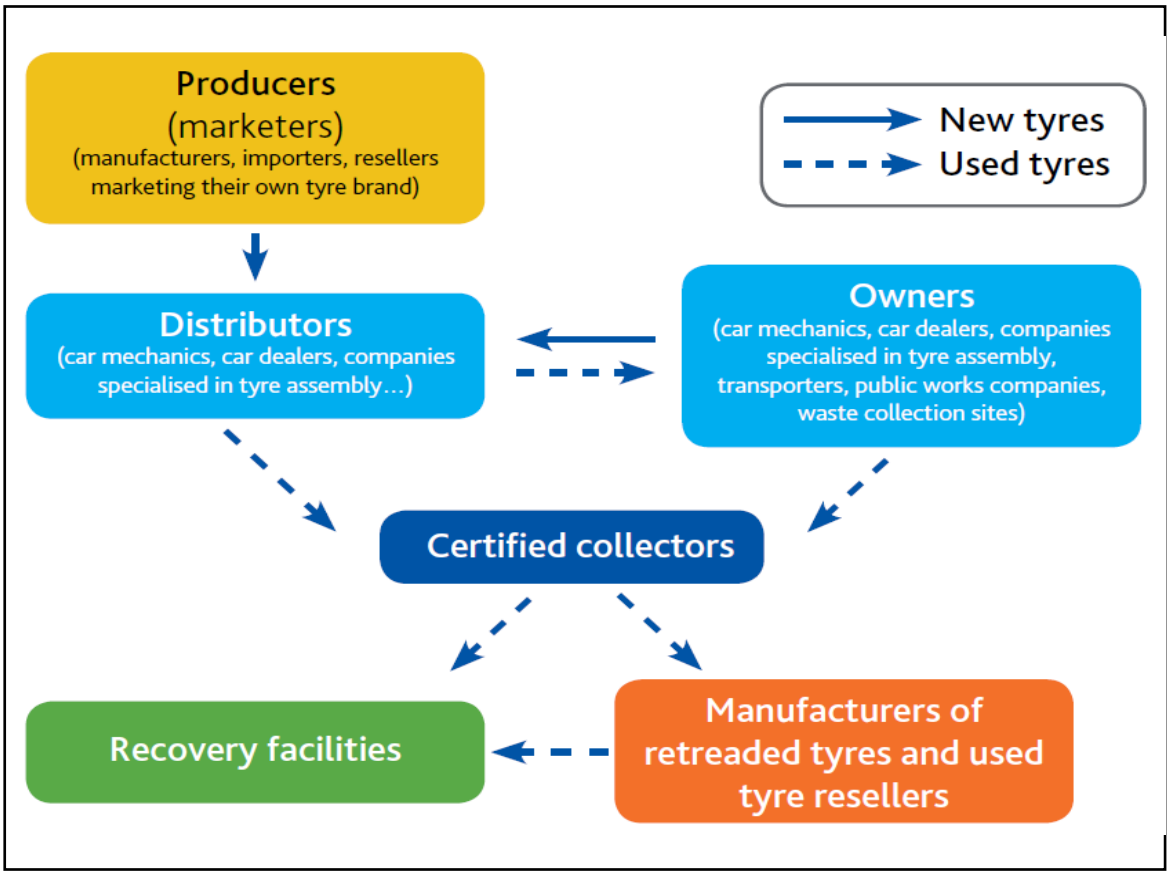
Figure 2.13 Producer Responsibility System Process



Source: Adapted from ETRMA (2011).

For example, as a successful case study of producer responsibility, France adopted a Producer Responsibility system, as it ranked as one of the largest countries in Europe for waste tyre production. In addition, France has the largest producer responsibility scheme in EU, which is organised by Aliapur (as a non-profit company) founded by the tyre manufacturers such as Bridgestone, Continental, Dunlop, Goodyear, Kleber, Michelin and Pirelli. There are other organisations in the same scheme, such as AFI –FRP, which act on behalf of the tyre importers' associations. The scheme is funded by the tyre producers, who report their production in figures and pay the resultant fee on a monthly basis. The fee depends on the tyres' weight/kg. These taxes are included in the price of the new tyre and hence are passed on to the consumer (WRAP, 2008). Figure 2.14 illustrates the main actors and flows in the used tyre sector.

Figure 2.14 Main Actors and Flows in the Used Tyre Sector

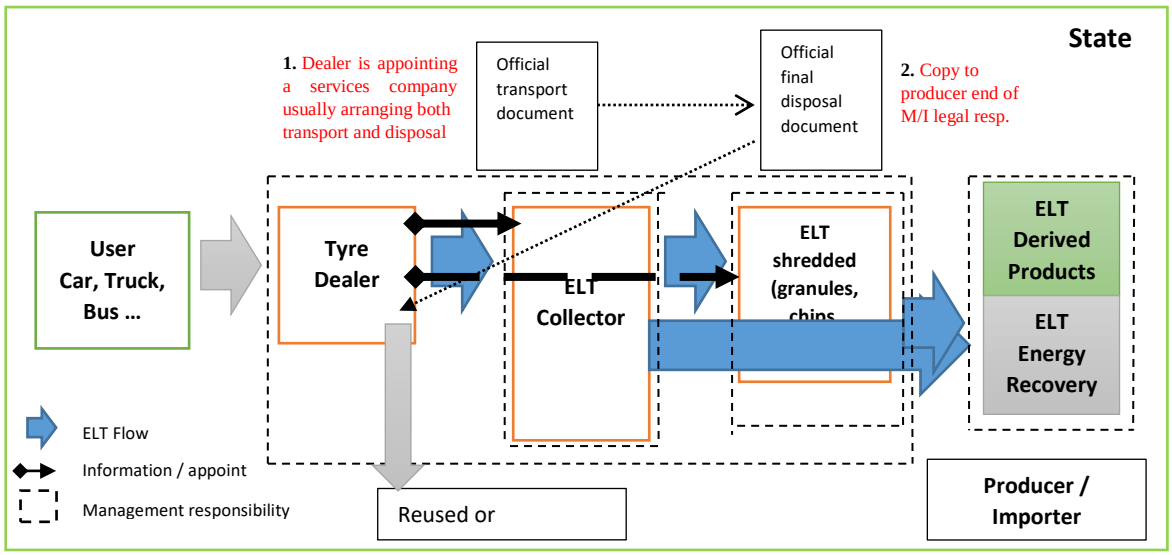


Source: ADEME (2014).

2.6.2.3. Free Market System (FMS)

The FMS represents the so-called producer responsibility as a voluntary approach (see Figure 2.15). This economic system allows for setting prices for goods and services and depends on the consent between sellers and consumers. In other words, all voluntary exchanges that take place in a given economic environment in which the laws and powers of supply and demand are free from any interference by the government (Copp, 2008; Sienkiewicz et al., 2012). In this context, the profitability that comes from recycling and recovery of used tyres - which in itself is a valuable source for raw materials - is a profit for firms involved (Sienkiewicz et al., 2012). FMS are less attractive in spite of their simplicity (Sienkiewicz et al., 2012; Torretta et al., 2015).

Figure 2.15 Free Market System (FMS)



Source: Adapted from ETRMA (2011).

The systems used in Austria and the UK are examples of a free market/ voluntary approach. For example, in the UK, the Responsible Recycler Scheme (RRS) is a voluntary scheme set up in 1999 by the Tyre Industry Council (TIC) in order to demonstrate to the UK government that tyre manufacturers were dealing responsibly with waste tyre management. In this regard, independent auditors monitor participants in the scheme annually and award a certificate, which can be used as a marketing tool to reassure customers that tyres are being disposed of responsibly. The certificate is issued by a scheme operator at the site (the certificate is called a Tyre Recovery Note) for each metric tonne of waste tyres processed. The costs of the scheme are recovered by a charge paid by the members (WRAP 2008; Sakai et al., 2011). Note that the fees (whether visible or invisible) are charged to the consumer when purchasing a new tyre for a used one, to regulate the suitable treatment and safe disposal (WRAP, 2008).

Overall, the Northern European countries have achieved significant progress in waste management and moved away from landfill due to the Landfill Directives and Waste Framework Directive (2008) which aim to strengthen the waste management hierarchy (Pires et al., 2011; Williams, 2015). Many of the member countries of the EU have changed their policy and institutional context and built a strategy based on processing techniques instead of the landfill. In addition, the three economic systems schemes adopted by the EU have contributed to a rapid improvement in the recovery of waste tyres, which has reduced the accumulation of waste tyres at landfill (Sienkiewicz et al., 2012; Uruburu et al., 2013). Table 2.6 illustrates the achievement of waste tyre recovery in EU countries, according to the economic system schemes adopted by each country.

Table 2.6 Waste Tyres/ Part Worn Tyres/ ELTs Europe - Volume in 2012

National figures (tonnes)	Waste tyre/ unit	Reuse of part-worn tyres			Net of waste tyre arising	Waste tyre recycling	Waste tyre recovery for energy	Landfill/ Unknown	Total unit for recycling, recovery, reuse, export and retreated	% unit valorised and /or reused, exported or retreated
		Reuse	Export	Retreading						
	(A)	(B)	(C)	(D)	E=A-(B+C+D	(F)	(G)	(H)	(I)	J=I/A
Countries with producer responsibility										
France	416,000	45,000	0	48,000	323,000	148,000	175,000	0	416,000	100
Italy	403,000	24,000	19,000	30,000	330,000	119,000	191,000	20,000	383,000	95
Spain	280,000	5000	18,000	38,000	219,000	103,000	116,000	0	280,000	100
Belgium	80,000	1000	2000	11,000	66,000	54,000	12,000	0	80,000	100
Czech Rep.	56,000	0	0	2000	54,000	15,000	27,000	12,000	44,000	79
Estonia	12,000	0	0	1000	11,000	10,000	0	1000	11,000	92
Slovenia	10,000	0	0	0	10,000	5000	5000	0	10,000	100
Countries with free market										
Germany	605,000	10,000	93,000	78,000	424,000	190,000	234,000	0	605,000	100
UK	363,000	26,000	27,000	28,000	282,000	143,000	127,000	12,000	351,000	97
Austria	63,000	0	0	3000	60,000	24,000	36,000	0	63,000	100
Ireland	30,000	3000	1000	2000	24,000	11,000	10,000	3000	27,000	90
Countries with tax system										
Denmark	38,000	0	2000	0	36,000	36,000	0	0	38,000	100
Slovak Rep	24,000	0	0	1000	23,000	17,000	6000	0	24,000	100
Latvia	12,000	0	0	1000	11,000	5000	5000	1000	11,000	92

Source: Adapted from Torretta et al. (2015); ETRMA (2011); Dzene et al. (2010)

As observed from Table 2.6, most EU countries are using the producer responsibility system, which has achieved in some countries more than 100% of tyre recovery. As example, Belgium, France, and Portugal and Slovenia achieved 100% recovery; this is due to the advantage of transparency in the interpolation for imposed standards. While countries that used tax and the FMS have been less successful, in spite of the simplicity of this approach (Sienkiewicz et al., 2012; Torretta et al., 2015). Furthermore, the FMS (Voluntary systems) are particularly difficult to implement if there are many players in the tyre market and so, generally the European tyre industry promotes producer responsibility as mandatory systems, as they help to minimise the problem of "free-riders" and reduce uncertainty surrounding future legislation. Another advantage of mandatory policies is the creation of a clear set of rules for all players in the market (WRAP, 2008).

2.7. The Disparity in Transfer and Application of Waste Framework Directive in EU

The transfer of waste regulation from the EU level to the level of local laws and their implementation depends on each member of the EU. Although there has been a marked improvement over the last decade, as a whole in the EU there is a difference and a great variation among member countries of the EU in terms of the effort in the application of EU waste directives (Skovgaard et al., 2008). In particular, to prevent or reduce the adverse effects that landfill can have on the environment and human health, according to the Landfill Directive, there should be closures of these landfills and an increase in waste management levels, However, the disparity among countries in the implementation of these directives is clear (Skovgaard et al., 2008; ETRMA, 2011). At this point, northern European countries have achieved significant progress in waste management and moved away from landfill, while the eastern and southern European countries have made less or no progress (Williams, 2015). For example, Austria, the Netherlands, Germany, France, Denmark and Sweden are no longer disposing of tyres in landfill, while in other countries such as Greece the proportion of disposal to landfill represents 5%, and Italy 5%, and 3% in the United Kingdom. This contrasts with Ireland, Bulgaria and Turkey where the proportions of disposal into landfill represent 10%, 31% and 36% respectively (Torretta et al., 2015).

Many of the member countries of the EU (e.g. Germany, France, Austria, Denmark and others) have changed their policy and institutional context and built a strategy based on processing techniques instead of the landfill. For instance, the EU has developed three different types of tyre management schemes represented in the PR system, TS, and FMS, which have contributed to rapid improvement in the recovery of waste tyres, and reduced

the accumulation of waste tyres at landfills. In this way, the countries that have adopted the producer responsibility system have achieved a significant recovery of waste tyres, reaching even 100% (Sienkiewicz et al., 2012; Uruburu et al., 2013). In contrast, there are many countries that are not able to achieve the fulfilment of the requirements and will be obligated to improve their waste management system in accordance with the specified time to reduce landfill policy. Williams (2015) states that the failure of EU policy implementation is a result of complex reasons, but includes the availability of financial, political and social will; technical skills; suitable planning and legal frameworks; and a wide range of other social, demographic, cultural and administrative factors. On the other hand, in some cases, it appears that the national government has no authority to impose the implementation of environmental policies at the local level, which may not then be applied if there is an absence of joint commitment to these policies in the relevant local authority (Mazzanti & Zoboli, 2008).

Despite the disparity in the implementation of environmental policy in the countries of the EU, for the various reasons stated previously, the EU is still ongoing in the development of environmental policies and strategy, aiming always to improve its waste strategy. Since the EU proposed improving its waste strategy, it has explored ways in which it might be losing significant opportunities to improve resource efficiency from waste, and for this reason, the EU has set a proposal for the next stage in waste management and the setting of targets beyond 2020. From the point of view of the European Commission, which considers waste as a raw material source, they found the Union's economy is currently losing a significant amount of potential secondary raw materials, which are found in waste streams, and are estimated to be more than 500 million tonnes of waste lost annually. Therefore, the European Commission has adopted a proposal related to revising a package of legislation concerning waste in order to move forwards into a circular economy, which will boost global competitiveness as well as promoting a sustainable economic growth and generating new jobs, in addition to reducing greenhouse gas emissions. The revised proposed legislation aims to reduce waste by establishing a credible long-term path for waste management and recycling (European Commission, 2016a).

According to the plans mentioned above, the European Commission (2016a) announced the main targets that are enshrined in their revised proposal:

- Recycling 65% of municipal waste by 2030;
- Recycling 75% of packaging waste by 2030;

- A binding landfill target to reduce landfill to a maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste; promotion of economic instruments to discourage landfilling;

The EU's policy priorities can be defined as: simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU; concrete measures to promote re-use and stimulate industrial symbiosis – turning one industry's by-product into another industry's raw material; economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

2.8. Producer Responsibility for Waste Tyre Management in Global South Countries

Today, most OECD countries and many emerging economies have EPR programmes and policies in place. Such programmes are also in the scoping stage in some Global South countries in Asia, Africa and South America. Nonetheless, the specific features and outcomes of these measures vary significantly across regions, countries and industries. For example, many Global South countries applied EPR, such as Brazil in Latin America and South Africa in Africa (Milanez & Bührs, 2009; Sebola et al., 2018; Oliveira Neto et al., 2019).

2.8.1. Waste Tyre Management in Brazil

The waste tyre management scheme in Brazil is based on the producer's responsibility, which is conceptually close to the system that exists in the EU. For the collection of waste tyres, there is some formalized infrastructure within Brazil. In 1999, the Brazilian National Environment Commission (CONAMA) determined that the manufacturers and importers of tyres were responsible for the collection and management of waste tyres in an environmentally friendly way. The regulation has evolved over time but has, in essence, maintained that recycling tyres is mandatory by law and is, therefore, the responsibility of the manufacturers. Brazil requires importers to demonstrate the disposal of 20% more tyres per year than they import (Milanez & Bührs, 2009; Oliveira Neto et al., 2019).

2.8.2. Waste Tyre Management in South Africa

The waste tyre management scheme in South Africa is based on the producer's responsibility. South Africa has formal regulations on waste tyres that govern the industry. Currently, the management of waste tyre in South Africa is based on the National Environmental

Management: Waste Act of 2008, Act No. 59 of 2008. All provinces of the Republic of South Africa are bound by these regulations to regulate waste tyre management. Waste type management options include Reuse, recycling for waste tyre and energy recovery, and duties of tyre producers and tyre dealers and integrated industry waste tyre management plans. In the year 2012, South Africa's Recycling and Economic Development Initiative (REDISA) set an integrated industry waste tyre management plan. The plan supports and enhances tyre recycling. It also provides for the collection and depot infrastructure required to collect tyre waste and deliver them to approved recyclers. REDISA was registered as a non-profit organization. Under the REDISA plan, every producer and importer of tyres had to pay a contribution fee to REDISA, which is used to facilitate the collection, transport, distribution and storage of these waste tyres. In this regards, South Africa achieved a recovery rate of waste tyres by the method of re-use of up to 25% of the market, shredding (23%), incineration (16%), pyrolysis (18%) and landfill (18%) (Sebola et al., 2018).

To summarize, at the present time there are many different approaches to develop appropriate strategies to enhance the efficiency of waste tyre management, in accordance with the applicable requirements of environment protection. This is a challenge mainly due to a lack of suitable regulations covering recovery of these wastes and the ever growing amount of waste tyre materials. However, in the case of car tyres, achieving a full success in the management of tyre wastes is possible. As recently demonstrated, there has been great progress in the development of innovative technologies improving management of waste tyres in the EU. Nowadays, in many countries of the EU, the level of recovery and recycling of used tyres is near 100%. This is possible due to the EU's restrictive legal regulations (Directive on the Landfill of Waste 1999/31/EC and End of life Vehicle 2000/53/EC), which prohibit stockpiling of tyres in landfills.

There are three models followed to assist in improvement of used tyre management in EU countries: they are all a development of organizational solutions based on the concept of extended producer responsibility for products (Extended Produced Responsibility), tax system, and FMS. In Europe, the most popular model is the one based on EPR, which legally obligates producers and importers of tyres to collect and then ensure recovery and recycling of the entire quantity of tyres placed on the market in a given year. The producers of tyres probably would not be interested in recovering and recycling tyres if a new law requiring them to do so did not exist. The new regulations caused increased investment in modern tyre sorting and collection systems and spawned innovative methods to enhance recovery

efficiency. Material recycling and combustion of used tyres are currently the most technologically developed methods of handling these wastes in the EU. It is worth pointing out that (from an economic point of view) tyre combustion and energy recovery is more attractive than material recycling. However, less energy is produced from combustion process of waste tyres than is needed for production of tyres. Therefore, material recycling of waste tyres and using them as a source of raw materials seems to be a better method than combustion.

Moreover, through using a grinding processes for waste tyres, they can become a source of valuable raw materials. In this way, tyres can be reused to produce different kinds of very valuable polymer composites, obtained mainly with the aid of natural and synthetic rubbers, polyethylene, polypropylene and polyvinyl chloride. The advantages of using ground waste tyres for production of polymer composites include cost reduction of such composites and the ability to classify them as a pro-ecological material. When using ground rubber as a raw material, it is possible to obtain completely new types of commercial polymer materials. Therefore, in today's environment, used tyres should no longer be considered a pollutant, but rather a valuable raw material.

2.9. General Directions and Outcomes of the Solid Waste Strategies in Global South Countries

2.9.1. Overview of Waste Management in Global South Countries

Rising populations, a booming economy, rapid urbanization, and rising standards of living in the community have significantly accelerated the rate of municipal solid waste generation in Global South countries (Minghua et al., 2009). Municipalities, typically responsible for waste disposal in cities, need to have adequate and reliable infrastructure for the population. However, they frequently face challenges beyond the capacity of the local authority to resolve (Sujauddin et al., 2008), primarily due to lack of financial resources, organization, complication and multi-dimensionality of the system (Abumoghli & Goncalves., 2020).

In fact, most governments in Global South countries recognise that rapid population growth overwhelms most of the municipal authorities' ability to provide basic services, and they are still struggling to cope with the collection and treatment of solid waste from all the cities' residents (Zurbrugg, 2003). According to Wilson et al. (2012), between 30-60% of urban solid waste in Global South countries is not collected and less than 50% of the population is served. One of the difficulties facing the Global South countries is a lack of servicing

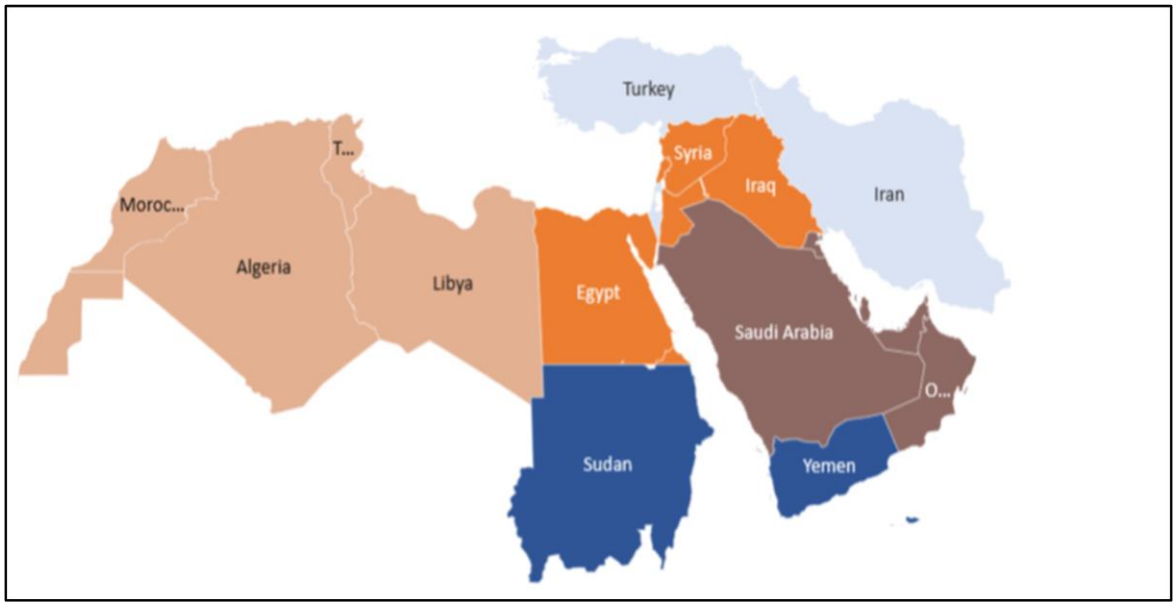
collection of solid waste disposal (Coffey and Coad, 2010). In the absence of regular solid waste collection services, this leads to the illegal disposal of waste in open places on the roads and along waterways and valleys, and on the banks of rivers, where waste then becomes fertile ground for the spread of disease and rodents. Moreover, the lack of sanitary landfills leads to the leachate of decomposing waste leaking into the ground, causing contamination to the soil and water, which is a common occurrence in many cities in Global South countries (Al-Khatib et al., 2007). Guerrero et al. (2013) present the results of a study in more than thirty urban areas in 22 Global South countries around the world to discuss the factors that affect the performance of waste management in cities. The researchers found that the amount of solid waste generated, which is less in Global South countries is often linked to the economic situation. In terms of waste segregation, the results reveal there is limited knowledge of the technologies of sound waste management practices, with a lack of resources to collect items that have been sorted, and absence of decision-makers who are interested in environmental issues. In terms of the financial system, the results show the decline in the number of service users who pay a fee for waste collection when compared with advanced countries. In the same study, it was found that the most common locations for the final waste disposal in cities were open dumps, where there are no facilities to protect the Earth from contaminants released from the waste. Most Global South countries including Arab and African countries are mixing recyclable materials such as plastic, glass, paper, metal and textile units, with domestic waste and other types of waste when collected, which increases the amount of municipal waste created (Wilson et al., 2006).

2.9.2. The Current Situation of Solid Waste Problem in the MENA Region

The common features of Global South countries are high population growth, rapid urbanisation and rising living standards of the community (in some countries), which have all accelerated the rate of solid waste production (Guerrero et al., 2013); this is particularly pertinent in Africa and Tunisia, with cities growing at an alarming rate (Chipungu et al., 2015). Similarly, the MENA region includes 21 countries (see figure 2.16), located in four sub-groups: the Mashreq region (Egypt, Iraq, Jordan, Lebanon, Palestine, Syria), the Maghreb region (Algeria, Libya, Morocco and Tunisia), the Gulf Cooperation Council Countries (Bahrein, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates), and the fourth cluster including Arab Least Developed Countries (Sudan, Yemen). In addition, the countries of Israel, Turkey and Iran generally stand separately; however, all share a common context of critical environmental challenges, in spite of their heterogeneous

characteristics in terms of geography, natural resources, political and social structures, and income levels (Abumoghli & Goncalves, 2020).

Figure 2.16 Shows Five Sub-Groups of Countries in the MENA Region



Source: Abumoghli & Goncalves (2020).

The MENA region is home to around 6% of the world's total population. The overall population of the area has risen from around 100 million in 1950 (Nassour et al., 2016) to around 437 million in 2016 (Kaza et al., 2018). The total area of the MENA field is approximately 11.1 million km2. Most MENA countries can be categorized as Global South countries, excluding Saudi Arabia, the United Arab Emirates, Qatar and Kuwait, which are classified as developed countries (Nassour et al., 2016).

Population growth, particularly in coastal areas, means urban centres generate many environmental pressures resulting from the increased demand for water and energy resources, as well as generating air and water pollution with respect to the discharge of sewage or sewage flooding and waste generation, land consumption and degradation of habitats, landscapes and natural coast (Abumoghli and Goncalves, 2020; Kaza et al., 2018). There is a significant difference between Global South countries and Global North countries (relevant to the MENA region) in the treatment and handling of solid waste materials (Zyoud et al., 2015). Trends in the field of solid waste generation in The MENA region indicate an increase in waste production per capita; the generation of per capita municipal waste output in most of its countries of more than 2 kg per day on average (Zafar, 2016). Solid waste

generation is projected to reach 200 million tons annually in 2020 due to population and economic development, increased urbanization, rapid industrialization, changes in habits of consumption patterns, and a lack of public awareness (El-Sherbiny et al., 2011; Zyoud et al., 2015).

In fact, in the MENA region cities spend about 20 to 50 per cent of their budgets on solid waste treatment. Unfortunately, there is little sustainable disposal of solid waste. Despite the fact that 80 per cent of the solid waste produced is decomposable, less than 5 per cent is recycled and less than 20 per cent is properly treated. The cost of the solid waste issues in the MENA region in terms of damage was approximately 0.3 per cent of the overall GDP in 2006 (UNEP-IETC, 1996; El-Sherbiny et al., 2011; Ismail, 2012). MENA's rising solid waste issue has begun to urge officials and environmentalists to come up with new alternatives, such as pay-as-you-throw scheme (Giannozzi, 2018; Aden, 2017). Most governments in the MENA region have recognised solid waste issues and they want to apply appropriate solutions (Nassour et al., 2016). Rising environmental consciousness in the MENA region today means that environmental protection has risen in importance in the political agenda. However, the SWM sector in the MENA region is unorganized and inefficient, and the various waste management strategies are still in their early stages (El-Sherbiny et al., 2011).

Despite the projected rise in solid waste generation in the MENA region by 2020, research conducted in the MENA region on the management of the solid waste issue remains inadequate. An analysis study conducted by Zyoud et al (2015) found that from 1982 to 2012 a total of 382 research papers were published by writers in the SWM field in the MENA region and it was noted that the number of publications increased rapidly in the last decade of this period. In this regard, the largest number of publications focused on Egypt, followed by Tunisia and Jordan, and the most active institution for publications in the MENA region was the American University of Beirut (AUB) in Lebanon.

2.9.3. Key Causes and Barriers of the Solid Waste Problem in Global South Countries, including the MENA Region

The causes and barriers facing the waste sector on the level of Arab and African countries are mainly due to the weak capacity of institutions in promoting the economic/financial, political and social aspects of waste management (Al-Yousfi, 2004). In addition, Nassour et al. (2016) stated that most of the Arab countries rely heavily on non-renewable resources,

meaning the waste resource sector in these countries is inadequately structured and regulated, and they have not yet established proper legislation or long-term strategy to promote waste sustainability. The main issues facing waste management in these regions is represented in the centralisation of power at the national level, the lack of effective mechanisms to recover costs, lack of trained staff, inequality of services between rural and urban areas and the lack of a reliable database. Similarly, various researchers have investigated the main reasons for the issue of solid waste in the MENA region and describe similar problems (UNEP, 2009; El-Sherbiny et al., 2011; Ismail, 2012; Zafar, 2016; Nassour et al., 2016; Aden, 2017). Whereas on the level of Global South Countries, meaning those classified under categories of low/middle income countries, such nations face many barriers that prevent SWM from becoming sustainable. Guerrero et al. (2013) grouped these causes and barriers into the following categories: technical, environmental, financial/economic, socio-cultural, institutional/organizational and political/ legal. Further studies confirm these causes and barriers and describe similar problems within each category (Cointreau-Levine, 1994; Ogawa, 1996; Troschinetz and Mihelcic, 2009; Coffey and Coad, 2010; Ezeah and Roberts, 2012; Wang and Geng, 2012; Guerrero et al., 2013). Table 2.7 summarizes the reasons and barriers that militate against SWM efforts in Global South countries, including the MENA region.

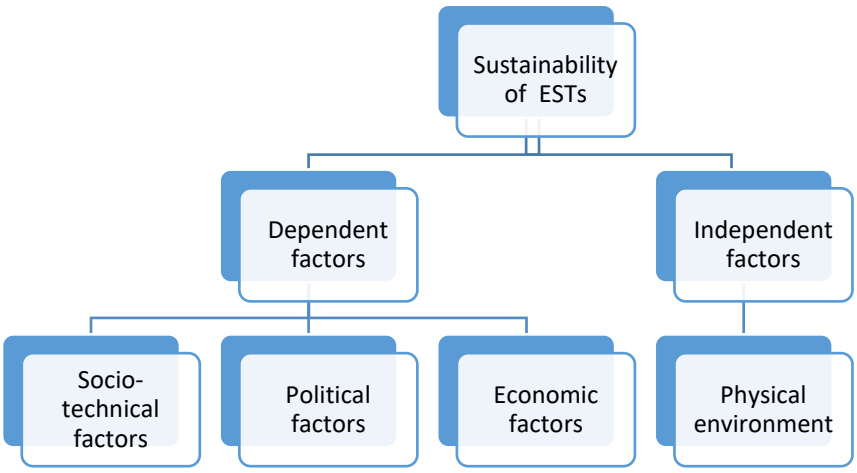
Table 2.7 Illustrates the Reasons/Barriers that Militate Against SWM Efforts in Global South Countries Includes the MENA Region

Main Reasons and Barriers at the level of Global South Countries (low-middle income countries)	**Main reasons and barriers at the level of MENA region**	**Some further explanation of reasons and barriers at the level of the MENA region**
• Absence of adequate policies, clear legislation and strong regulations (Guerrero et al., 2013) • Fragmented waste legislation; lack of many important elements (technologies, cost-effective aspects, enforcement mechanisms) (Guerrero et al., 2013; Troschinetz and Mihelcic, 2009; Ezeah and Roberts, 2012) • Budgetary constraints, lack of economic support from the central government, weak strategies for raising funds from residents, inappropriate economic and financial planning (Ezeah and Roberts, 2012; Guerrero et al., 2013; Troschinetz and Mihelcic, 2009; Coffey and Coad, 2010; Cointreau-Levine, 1994; Ogawa, 1996) • Lack of organizational capacities and managerial skills (leadership) of local authorities (Guerrero et al., 2013; Wang and Geng, 2012; Troschinetz and Mihelcic, 2009) • Perception that environment protection conflicts with national economic goals (Wang and Geng, 2012) • Sharing of similar roles and responsibilities, confusion regarding their delineation and distribution. Cross-agency collaboration rare (Wang and Geng, 2012) • Lack of educational and awareness campaigns regarding the importance of a proper waste management system and the role of citizens as waste generators (Guerrero et al., 2013; Wang and Geng, 2012) • Social rejection and low status of recycling jobs. Disrespect for waste work, producing low ethics and poor quality of work (Ogawa, 1996; Guerrero et al., 2013) • Unavailability of technology and/or human workforce, lack of skilled personnel with technical expertise on waste management, lack of technology, deficient waste equipment and structures (waste transfer stations, storages, old waste vehicles, etc.), poor roads, unreliable data and lack of information- sharing between stakeholders (Troschinetz and Mihelcic, 2009; Guerrero et al., 2013; Wang and Geng, 2012; Ezeah and Roberts, 2012)	• Lack of integrated sustainable solid waste management plans (UNEP, 2009; El-Sherbiny et al., 2011; Ismail, 2012; Zafar, 2016; Nassour et al., 2016; Aden, 2017). • Lack of strict measures and actions in the SWM sector (UNEP, 2009; El-Sherbiny et al., 2011; Ismail, 2012; Zafar, 2016; Nassour et al., 2016). • Instability of political conditions in the MENA region (UNEP, 2009; El-Sherbiny et al., 2011; Ismail, 2012; Nassour et al., 2016). • Insufficient allocated funds, lack of coordination among stakeholders, shortage of trained and qualified personnel, and shortage in technical and operational decision making (UNEP, 2009; El-Sherbiny et al., 2011; Zafar, 2016; Nassour et al., 2016; Aden, 2017). • Dumping of solid waste in open and uncontrolled spaces (UNEP, 2009; El-Sherbiny et al., 2011; Zafar, 2016; Nassour et al., 2016). • Limited public awareness about environmental issues, waste management practices and waste reduction, and sustainable living (UNEP, 2009; El-Sherbiny et al., 2011; Zafar, 2016; Aden, 2017). • Scarcity in reliable data of hazardous waste and waste-producing activities in the region (UNEP, 2009; El-Sherbiny et al., 2011; Nassour et al., 2016). • Lack of engagement of the informal Sector in the waste management systems by the government (Gunsilius, 2011; Scheinberg, 2012; Mostafa, 2020). • Lack of proper means of SW collection, transport systems, and balanced and adequate coverage of waste management (El-Sherbiny et al., 2011; Zafar, 2016).	• The MENA region lacks SWM plans which focus on the main 4Rs of waste minimisation strategies (i.e., reduce, reuse, recycle, and recover). No focus on prevention/reduction. Reuse, recycle, and recover in their infancy in most MENA countries. • Shortage of waste management legislation and poor planning for SWM. Lack in legislative frameworks, policies, strategies, and enforced laws and regulations for sustainable SWA in MENA countries. • Lack of sustainable economic instruments to calculate appropriate service fees for SWM. Most Local governments plan short-term, neglecting long-term SWM strategies. Staff not provided necessary training for a successful SWM programme. • • SWM dumping common throughout the MENA region leading to hazardous environmental pollution. SWM often burnt in the open-air. leading to air pollution • • The public awareness critically needed to raise awareness of the growing SWM problem. • The informal sector not considered by most governments of Global South countries, despite its positive major role in economic and environment sector. Citizens and authorities often hostile to informal waste-workers.

2.10. The Appropriate Options for Environmentally Sound Technologies (ESTs)

Firstly, there are several factors that determine whether SWM activities are sustainable or not. For example, Guerrero et al. (2013) presented several factors that influence the performance of the SWM system, highlighting that there are important elements to consider when choosing technology procedures to suit the particular society in terms of scale, type, and the ability to adapt. In this part, the concern only about the factors that influence the adoption of ESTs and to demonstrate how to be sustainable in a particular community (see Figure 2.17). These factors reflect particular social-cultural, economic, and political conditions (dependent factors). In addition, there are natural factors (independent factors) that represent a particular location for adopting ESTs; all of these factors are considered important for decision-makers.

Figure 2.17 Factors Influencing the Successful Adoption of ESTs



Source: Adapted from Dunmade (2002) and Al-Thawwad (2008).

2.10.1. Social, Cultural and Economic Factors

Each state has different principles in terms of culture, environmental conditions and work ethic, as well as a different rate of ability to adopt and implement elements that have a direct or indirect impact on the success or failure of the adoption of the technology (Al-Thawwad, 2008). Furthermore, perspectives and public perceptions in terms of culture in the selection and adoption of technologies differ from one country to another; for example, specific technology may be seen within one society as being environmentally sound, but then not in another (UNEP/DTIE/IETC, 1996). Mostly, Global South countries are guided by the technical approach only in the construction of waste management systems in terms of selection and adoption of technologies (Van de Klundert & Anschutz, 1999). However,

depending on the technical approach considered this is not a sufficient indicator to address the appropriate technological options. For example, it is known that practices in SWM in the activities of collection, transportation, storage and treatment in Global South countries at the present time are unsustainable, owing to the focus by the decision makers on the technical side only, and neglect of other important factors such as social-cultural, economic and environmental issues. For success in the SWM system, they need to address both the physical (technical) elements represented in collection, disposal, and recycling, as well as aspects of "soft" governance (such as inclusivity of both users and service providers), and to achieve a form of financial sustainability and strengthening of institutions to perform the public tasks (Wilson et al., 2013). Van de Klundert and Anschutz (1999) provide examples of waste management systems that failed in Global South countries for the reasons mentioned above. They recommend that the concerned authorities of the relevant waste management must consider other aspects such as social, political, financial and environmental aspects during the selection and adoption of technologies, in order to reach a more environmentally sustainable system. Others scientists support these recommendations; for example, Madu (1989), who declares that the transfer of technologies from Global North countries to Global South countries, whether hardware or know-how, has economic and social consequences related to its status in that country. Consequently, the degree of success for the assimilation of sociocultural, economic, environmental and political factors depends on national and local capability, which facilitates the adoption process for decision-makers (Luken & Van Rompaey, 2008).

2.10.2. Physical Environmental Factors and Environmental Technological Performance

The main targets for SWM strategies are to address health, environment, and aesthetics, as well as the use of land as a resource, and economic worries associated with the unsafe disposal of the waste (Henry et al., 2006). These issues are a source of constant concern to nations, municipalities, companies and individuals all over the world (Marshall & Farahbakhsh, 2013).

Nowadays, the interest in the environment has become part of the culture of Global South countries, where reports have become alarming due to growing environmental problems, such as global warming, ozone depletion, land degradation and green spaces etc. For Global South countries, this has economic repercussions. For example, Niger’s economy relies heavily on foreign technologies in order to help develop and maintain its water supply,

energy supply, health care facilities, and telecommunications projects, and other industrial projects such as iron and steel, petroleum refining, mining and other projects. Despite the fact that foreign technology investment flows into the country, many of these projects have failed after a few years, or some of them fail even before completion, and some of the other projects fail shortly after the end of the agreed contract "grace period ". The result is that many of the projects have become environmental menaces wasting huge amounts of resources. The reason for the failure in many cases is partly down to the decision-makers and their unwillingness to conduct adequate pre-investment evaluations in terms of environmental, economic, and social aspects to make schemes sustainable within the local community (Dunmade, 2002).

In the same context, Dunmade (2002) presented an example of the challenges to the environment in the Delta region in Niger for producing energy from power stations, which relied on non-sustainable technologies, and where environmental deterioration caused by oil and gas spills have occurred, causing deforestation. This level of environmental degradation cannot continue indefinitely, because the environment is no longer bearing this burden, so Niger should seek to avoid the occurrence of such environmental problems. For this reason, Dunmade (2002) recommends when choosing, adopting or proposing any technology, it is necessary to assess their impact on the environment first.

Therefore, one of the main policy tools that must be considered for environmental sustainability is the physical environment and assessing the environmental performance of the techniques. The physical environment, in terms of "terrain, climate, and weather", are considered important factors, which must be viewed in the selection of technologies to achieve the concept of ESTs (Al-Thawwad, 2008). On the other hand, the evaluation of the environmental technology's performance is another important factor. In this context, Duangburong et al. (2015) stated that the evaluation of technologies for processing solid waste, particularly waste tyres, depends on environmental, social and economic factors. Thus, the selection and adoption of technologies depends on the evaluation of the environmental impacts of the selected technologies in terms of materials consumption, such as energy, water, or the safe final disposal of those consumption materials. In sum, the success of any technologies for the treatment of waste tyres or solid waste generally is dependent on an evaluation of environmental performance and the economic process that ensures sustainability (Muzenda & Popa, 2015). Such evaluations help decision-makers to make the right decisions to adopt technologies on the basis of their environmental

performance. Chang et al. (2011) stated there are many assessment tools that consider the aspects of economic and environmental spheres, such as systems analysis, analysis platforms and LCA, that can be used as decision support for planning, monitoring and improving the existing SWM systems.

Shifting away from landfill to reduce emissions, and promote the use of energy recovery from waste with the use of technologies that have fewer impacts on the environment, is one of the global concerns today. Climate change is an important motivation in all parts of the world - the Clean Development Mechanism under the Kyoto Protocol means that the Global North countries can buy "carbon credits" from developing nations, which contributes to providing a major source of income to encourage cities in Global South countries to improve waste management systems (Wilson, 2007). Indeed, MENA countries have realised their vulnerabilities. Therefore, almost every country in the region has submitted a plan for their contribution towards the global framework under the Paris Agreement that drives collective action toward a zero-carbon, climate-resilient future. Accordingly, many international initiatives have been launched to help countries with these national plans; for example, the MENA Climate Action Plan was launched to increase financing dedicated to climate action with a focus on protecting the poorest who are the most vulnerable (Dagnet et al., 2016; Sieghart & Betre, 2018).

2.11. Disposal Methods and Options

Various waste treatment options are currently available with varying levels of problem-solving and resource recovery facilities. Many of the options for waste treatment have some advantages, as well as some challenges in implementing them practically. There is no single technology that can completely solve the issue of waste management. It is therefore important to incorporate various waste management technologies in a strategic manner in order to achieve the objectives of sustainable waste management. However, it is difficult to choose a particular technology for sustainable waste management decision-making or policy-making process without understanding the various technologies and their environmental impacts. Owing to the lack of knowledge and information about the impacts of such technologies, sometimes an incorrect decision has been made which may lead to arise an adverse and crucial situation in the future. For that reason, it is important to know different technologies through a comparative analysis of different alternatives options and this may be a leading guide method for decision-making processes. In this regards, the LCA is one of the important instrument to assess different technologies (Zaman, 2009).

2.11.1. General Information on LCA and Systematic Review (SR)

As it is known, the tyres are composed of complex components from materials manufactured from vulcanized rubber and various other reinforcing materials. Nearly 1.5bn waste tyres are disposed of annually (Pilusa & Muzenda, 2016), which is beginning to attract the attention of many societies. Alternative options for their disposal include: reuse, retreading, regeneration, co-processing, pyrolysis, and recycling; however, the ideal alternative has yet to be established. LCA can utilized to quantify the impact of waste tyre disposal and determine the most environmentally beneficial alternative for used products. LCA has been applied to identify the most environmentally appropriate final destination for waste tyres (Clauzade et al., 2010; Farrell & Cavanagh, 2014; Ortíz-Rodríguez et al., 2017). LCA can be used to determine the best alternative for managing used products, encompassing their disposal, recycling, and reuse (Pennington et al., 2004). Scientific studies on LCA have been carried out on different continents over the world. LCA it is a wide appraisal that considers all the traits or aspects of the natural environment, from raw materials (natural resources) to human health. In order to standardize environmental management methodology, there is a tremendous development in learning in terms of harmonisation and standardisation that has been promoted by the Society for Toxicology and Environmental Chemistry and the International Organization for Standardization (ISO). ISO developed the ISO 14.040 global standard, which defines the method for LCA application (Guinée et al., 2002). According to the ISO, the framework of LCA includes four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation (Finkbeiner et al., 2006). Defining the goal and scope includes establishing the motives for the study, the intended application, and the target audience. The limits of the system under study are also described in this phase, in addition to defining the functional unit (Guinée et al., 2002), which is a quantitative measure of the functions that the products (or services) perform.

The results of the LCI provide information on the inputs (resources) and outputs (emissions) of the product during its life cycle, concerning the functional unit. The goal of the LCIA is to determine and assess the significance of the potential environmental impacts of the system studied. In this stage, the functional units allow the relevant data to be compared. Inventory data are divided or separated into midpoint and endpoint (resource consumption, ecosystem quality and human health,) and converted into units by weighting factors for comparison (Hauschild et al., 2013; Kägi et al., 2016).

The systematic review is a literature review that collects and critically analyses multiple research studies or papers, such as LCA studies related to end-of-life tyres. Moreover, a review of existing studies is often faster and cheaper than embarking on a new study. Tranfield et al. (2003) state that systematic reviews are a tool for further developing the knowledge base to provide the best evidence for informing policy and practice in any discipline, and replaces the traditional review (narrative) that often lacks accuracy. Furthermore, the systematic review is a method that allows the researcher to learn from what others have already studied and what has been discovered, then evaluate and summarise the findings of all relevant studies, to establish reliable evidence to facilitate decision-making and advances in the field (Gough et al., 2012).

The major advantages of systematic reviews are reduced bias, replicability, and the potential to solve controversy between conflicting findings, as well as providing information through a wide range of empirical methods to provide a reliable basis for decision making (Gough et al., 2012; Mallett et al., 2012). On the other hand, the systematic review has disadvantages, as it requires access to a wide range of databases that may be problematic in terms of being very expensive for non-academic researchers. In addition, often the relevant research study is located outside the formal peer-reviewed channels (Kitchenham, 2004; Gough et al., 2012; Mallett et al., 2012; Zumsteg et al., 2012).

The most sustainable final destination for end-of-life tyres is difficult to determine among the different possibilities available. The LCA tool has contributed to the decision-making process, requiring different technologies for each situation and condition. As such, the aim of this part is to present an overview of the use of LCA in order to investigate tyre disposal options and determine the most environmentally beneficial alternative. Studies of LCA for waste tyres have been reviewed and the environmental impact of each technology evaluated, according to systematic review.

2.11.2. End-of-Life Tyre Destination from a LCA Perspective

At the end of a tyre's life cycle, the tyre becomes waste with other waste streams, and the waste management of post-consumed tyres is a difficult task because of their physical properties and chemical constituents (Karagiannidis and Kasampalis, 2010). Selecting the ultimate destination of tyres requires significant knowledge and responsibility, since improper disposal can result in extensive negative impacts, including fires that cause air pollution, or unsanitary waste dumps and therefore the proliferation of mosquitoes. In

keeping with the waste hierarchy, there are a few ways of disposing of waste tyres to alleviate environmental impacts, the most common being reuse, regeneration, retreading, co-processing, pyrolysis, and landfills (Williams, 2005; ETRMA, 2011; Van Ewijk and Stegemann, 2016).

2.11.2.1. Reuse

Reuse involves using the whole tyre or grinding it into pieces to manufacture different elastic items for application. The applications can be used for roadside hindrances, the development of parks and playgrounds areas, marine protection structures (such as wharves, dams and for waterfront regulation etc.), channelling rainwater, artificial reefs (offer habitats for organisms as the natural home such as corals and algae), and biogas waste (Clauzade et al., 2010; Karagiannidis & Kasampalis, 2010; Uruburu et al., 2013; Torretta, 2015)

2.11.2.2. Reforming

Tyre reforming, also known as "remould", can be achieved via three different re-manufacturing processes, in particular recapping, retreading, and remoulding. All include replacing one or more worn regions with crude rubber and submitting them to revulcanization to obtain the properties of another new tyre. Recapping consists of replacing the tread on worn tyres: retreading replaces both the tread and its shoulder; and remoulding, otherwise called bead-to-bead retreading, which involves replacing the tread, shoulder, and whole sidewall surface (Jang et al., 1998).

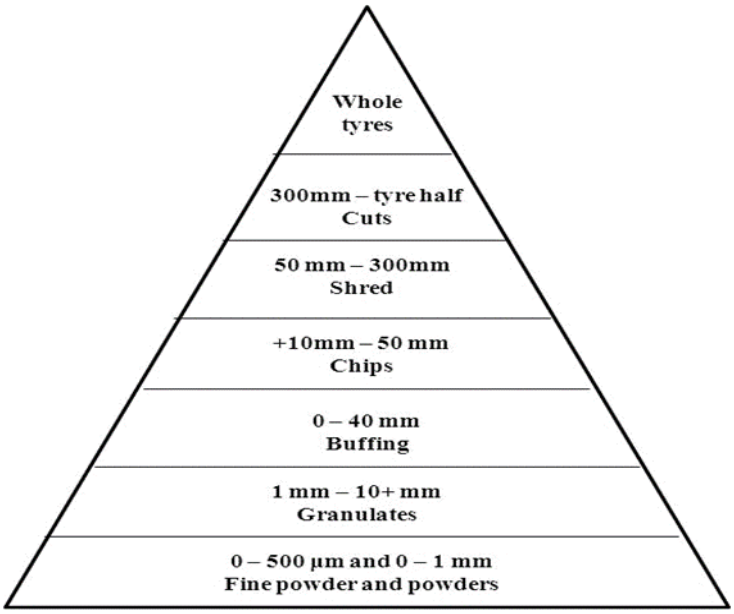
Reforming is a fascinating approach for used tyre recovery, because it promotes financial savings in iron, rubber, and petroliferous resources and minimizes the issues related with the removal of used tyres (Ferrão, 2008; Van Beukering and Janssen, 2001). Reforming is used especially in the truck tyre market, which can be retreaded more than three or 4 times (Van Beukering and Janssen, 2001). Retreading additionally gives electricity financial savings because the power required to manufacture a new tyre is around 2.3 times higher than that required for retreading (Van Beukering and Janssen, 2001; Ferrão, 2008).

Grinding tyre rubber;

Used tyres or pre-treated tyres that cannot be used for their original purpose and therefore become waste, can instead be used to produce rubber crumb or granulates, which depending on the technology used during the process, include materials produced from two main techniques of grinding:

- Mechanical grinding, meaning the use of knives to reduce scrap tyres or rubber waste into various particle sizes by recovering the materials of steel and textile. After the first process of grinding it goes through a shredder, which produces material of particle size 50–300 mm, then chipping for further fractions to reduce the material to a size of 10-50 mm. Figure 2.18 illustrates size-reduced materials from 0.01 mm to > 300 mm in size (Karagiannidis & Kasampalis, 2010; Li, 2010; Muzenda, 2014).

Figure 2.18 The Triangle of Terminology Shows a Range of Size Reduced Materials from Rubber Tyres



Source: (Karagiannidis & Kasampalis, 2010, p.522)

- Cryogenic grinding involves using liquid nitrogen for cooling rubber at a temperature on average between - 60 to - 100 °C, where the rubber becomes brittle and is easily reduced to fine particle sizes from 30 to 100 mesh, using a hammer mill (Adhikari, 2000; Karagiannidis & Kasampalis, 2010; Li et al, 2010; Muzenda, 2014).
- Wet grinding is a rarely utilised process, which produces tiny rubber particles that are further reduced in size by grinding them into a liquid medium, usually water. The surface characteristics and form of the particles produced from this system empower this product to be more effectively and successfully integrated into other polymer materials (Ramos, 2011; Lo Presti, 2013; Uruburu et al., 2013). In general, the advantages of wet grinding are that it generates recyclable rubber and is useful to produce other materials such as steel and textiles, which can also be recycled (Torretta et al., 2015). In this context, there

is a multi-application of grinder techniques to use for generating new products, particularly in civil engineering such as flooring for playgrounds and sports stadiums, as well as a promising use in the construction of artificial turf, in asphalt applications and many others (Karagiannidis & Kasampalis, 2010; Torretta et al., 2015). In contrast, there are drawbacks of the wet and the cryogenic grinding system, as it requires a drying time, which that can cause the leaching of Zinc oxide “ZnO", "which is a part of tyre additives" under certain environmental conditions (Lo Presti, 2013).

2.11.2.3. Regeneration of Tyre Rubber

In case of regeneration, waste tyres subject to chemical degradation (i.e. modification) turn out to be more plastic, pliable, less viscous, and processable; that is, with properties like those of virgin rubber. Regeneration prompts the breaking of covalent carbon-carbon (C-C), carbon-sulphur (C-S), and sulphur-sulphur (S-S) bonds. If a range of C-C bonds is broken throughout the process, the major rubber chain may rupture, leading to serious structural disintegration (Cui et al., 2016).

The products quality regenerated from waste tyres differ in accordance with their composition and the selectivity of the process used in terms of the type and number of bonds to be broken. For regenerated waste to be appropriate and good quality, at least 70% of cross-linking needs to be carried out. It has to also stay stable for at least six months and remain in this condition to have the ability to be revulcanized at temperatures close to 170°C. Rubber regeneration can be conducted in the presence of a unique catalyst, which assaults the cross-linking points, or by applying adequate energy to break down these bonds. This technique normally requires heat, chemical products, and mechanical energy. On a basic level, regeneration is used to gain a product to supplant virgin rubber with less technical requirements than the original product. Rubber is considered regenerated when it recovers its ability of flow and the characteristics of the original compound. Regenerated rubber can be utilized in floor coverings such as carpets, furniture, asphalt mixtures, glues, and adhesives (Pacheco et al., 2012).

2.11.2.4. Co-processing by Incineration in Cement Production Kilns

Co-processing is described as the use of waste materials to substitute fuels and/or main raw materials as called (Tyre-Derived Fuels TDF). Entire or ground tyres are incinerated in a cement kiln to produce clinker, an intermediate product in cement manufacturing. The ash generated is not risky since it integrated into the clinker, which prevents the need for

consequent collection and treatment (Fiksel et al., 2011). Iron and Silica (contained within the tyre) are utilized as secondary raw materials to supplant sand and iron oxide in cement. The high temperatures (1500–1600°C) and the environment of the oxidizing atmosphere within the cement production furnace permit total combustion of the tyre and nearly total combustion of the volatile material created amid burning (Amari et al., 1999; Clauzade et al., 2010; Karagiannidis & Kasampalis, 2010).

The tyres can be fed into the furnace (kiln) entire or in a ground form. Entire tyres must be fed into the calcination zone of the furnace, whereas ground tyres can be fed into the burner area (Silvestravičiūtė and Karaliūnaitė, 2006; Clauzade et al., 2010).

2.11.2.5. Co-processing in Energy Recovery

The energy recovery from waste tyres is considered one of the alternative options. The chemical composition of tyres contains hydrocarbon materials, making them the incentive provider for fuel energy to be used in industries (Machin et al., 2017). The use of fossil fuels, represented in the form of coal, oil, and gas, accounts for about 80% of worldwide energy demand (Muneer et al., 2005; Feraldi et al., 2013). Nitrogen compounds and sulphur oxides created by coal combustion have a significant impact on the environment and are responsible for acid formation at the atmosphere (acidification) and increase the level of ozone concentricity at low altitude (Webb & Hunter, 1998; Liu et al., 2015). Singh et al. (2009) stated that utilizing tyres as a source of material to produce power in coal-fired power plants decreases NOx emissions and recovers the energy held in the material. In this process, ground tyres are blended with coal in the combustion unit to produce electrical energy. The main advantage of this process is decreasing the consumption of fossil fuel (Fiksel et al., 2011). Notwithstanding, the energy transformation efficiency of power stations that utilize tyres as raw material is about 30%, which is lower than in traditional power stations. However, the emissions released by CO2 are around 23% lower when tyres are utilized for power generation (Fiksel et al., 2011).

2.11.2.6. Pyrolysis

Pyrolysis is a chemical process to retrieve resources from used tyres or scrap tyres regardless of their quality, in order to reduce the size of tyres under high temperatures (400–700°C) in the total absence of oxygen. The outcome of this process generates: carbon black (22%), aromatic oil (30%), gas (28%), scrap steel (10%) and 5% remains, comprising about 15% of the tyre volume, which is needed at the beginning of input power to run the process

(Karagiannidis & Kasampalis, 2010). The estimated yield of the products is variable according to the operating conditions that are used. The level of technical difficulty is the main obstacle for the implementation of a successful pyrolysis technique, which affects the economic feasibility and the quality of the product; for instance, the char by-products can be reprocessed into bad quality carbon black, which cannot be utilised as a source material (Adhikari, 2000; Li et al., 2010; Zabaniotou, 2014).

In relation to this, numerous businesses of pyrolytic plants have had a tendency to fail as a result of high capital and cost operation because of the low-grade quality of the end product and high contamination of these products, which consequently makes it difficult to find a market for them (Adhikari, 2000; Zaman et al., 2017). In general, all technologies have advantages and disadvantages. Pyrolysis technology has the advantage of being capable of reducing 90% of the volume of waste tyres with material recovery and breaking down most of the organic materials that cause harm to human health. In contrast, the technology has disadvantages or problems in terms of disposing of ash that contains within it lead and cadmium salts, and toxic gases such as SO2, H2S, HCl, HC, etc., generated when burning tyres, and which would require further treatment. However, in the case of uncompleted burning, this will lead to producing soot (Antoniou and Zabaniotou, 2013; Muzenda, 2014; Sharma, 2000).

2.11.2.7. Landfill Disposal

Landfill has traditionally been the most common method for waste disposal. The disposal of the tyres in landfill has a negative effect on the environment in terms of shortening the useful life of the landfill. This practice impoverishes the soil, favours the proliferation of mosquitos, and makes the site prone to fires (Ferrão, 2008; Van Beukering and Janssen, 2001). Fires caused by tyres are dangerous because they are difficult to extinguish. A tyre has around 75% of voided space in relation to its whole volume, which makes it difficult for these fires to be quenched with water since the oxygen in this space feeds the fire (Jang et al., 1998).

In the 1970s, the disposal of scrap tyres at landfill reached 70%. Later on, environmental awareness increased with the lack of site availability due to a rapid increase in the costs for such sites, which led to the development of laws and technologies. This in turn contributed to increasing the recovery of the scrap tyre. It is now expected that in the 21st century, most scrap tyres will be used for recycling, particularly after many countries have banned the disposal of scrap tyres in landfill (Adhikari, 2000; Van Beukering and Janssen, 2001; Ferrão,

2008). For instance, the EU prohibited discarding tyres in landfills, according to Directive Landfill of Waste 1999/31/EC and End of life Vehicle 2000/53/EC (Sienkiewicz et al., 2012).

The most sustainable final destination for end-of-life tyres is difficult to determine among the different possibilities of technology options available or policymaking processes without knowing the different technologies and their impacts on the environment. The LCA tool has contributed to the decision-making process, requiring different technologies for each situation and condition. As such, the aim of this part is to present an overview of management options described above. In order to determine the most environmentally beneficial alternative from these options, the LCA is used as a tool to investigate tyre disposal options in terms of most environmentally beneficial alternative. To that end of this chapter, studies of LCA for tyre disposal options were reviewed and the environmental impact of each technology was evaluated by using the systematic review, which has been guided by Boland et al. (Eds., 2013) and Zumsteg et al. (2012). The results of selected articles (as a basis for the methodology that follows) are presented in chapter four and discussed in chapter five**.**

CHAPTER THREE: RESEARCH METHODOLOGY

3.0. Methodology and Methods

This chapter outlines the general approach and specific techniques adopted to address the research objectives. It begins by discussing the existential and epistemological foundations of qualitative and quantitative research and arguments for and against combining the two approaches into one. The strengths and weaknesses of two opposing approaches are briefly indicated and the rationale for combining them in one study is explained. The chapter also presents the research design, methods used in selecting participants for this research, data collection, and how the data were analysed and interpreted. The chapter concludes by giving a view about the limitations of the methodology used in conducting this study. This study was conducted to assess the status of waste tyre management practice in Tunisia. Waste tyres management in Tunisia was chosen for this study because research on this waste stream is somewhat limited, and it is likely that most Global South countries including Tunisia lag behind in terms of the total volume of waste tyres generated, collected and processed. As there are no available systems and awareness programs about waste tyre management, the situation of its management is becoming a challenge in Tunisia.

The country has experienced rapid economic growth and an increasing trend in automobile ownership (Table 1.1), becoming a huge importer and consumer of tyres, with an expected increase in tyre sales and ultimate scrapping of tyres. In the late 1990s and early 21st century, new tyres entered the country every year, but most of them entered the country unofficially (AYADI, 2015). As such, these tyres are more likely to be discarded or replaced once they reach their end-of-life. Because there is a lack of strategies and mechanisms to facilitate reuse, recycling, recovery, regrooving, material recovery and energy recovery of ELTs, the unmanaged dumping of waste tyres is becoming a major environmental health concern, which may lead to the problems of dealing with waste tyres generation and its management.

There are other problems related to illegal dumping, such as fire hazards and the breeding of mosquitoes, which are a vector for serious diseases, making this a major topical issue. Therefore, this research forms the basis for the development of a strategic approach to the waste tyre management system in Tunisia, with some important aspects taken into consideration, namely: legal target fulfilment; the target of economic fulfilment through establishing recovery and recycling activities; the minimisation of the environmental health impacts; and the participation of the stakeholders.

According to what was reported by the Ministry of Industry, Energy and Mines, approximately forty brands of rubber tyres are purchased from major international firms outside Tunisia, the most important of which are as shown in Table 3.1. However, in Tunisia, tyre manufacturing is limited locally to one company, called Société Tunisienne des Industries de Pneumatiques (STIP). These importer companies are quite familiar with EPR and other environmental regulations.

Table 3.1 Brands of Rubber Tyres Purchased From Major International Firms outside Tunisia via Local Importers Companies

International brand rubber tyre in Tunisia	**Importers companies for local trade in Tunisia**
Michelin, GT Radial, Mitas, Lassa, Good Year, Petlas, Slideal, Continental, BKT, OZKA, Bridgestone, Henan, Hankook, Triangle, Nexen, Hero, Starmaxx, Cooper/Avon, Dunlop, Aeolus	Atlas lil'atwaq Company for Rubber, Jumaa and Partners Company, Tunisian Company for Wheels and Rubber Industrial (STPCI), Rubber Tyre Trading Company (SCP), Saleh Khalaf Allah Company and his sons, El Ghadhab Rubber Company and its affiliates (SPG), Sfaxien Bank for Rubber Wheels (CSPD), Al Wafa Rubber Company, Sfax atwaq Company, Maghreb Rubber Tyres Promotion Company (SOMACOP).

Source: The author

In addition to hundreds of local tyre distributors and traders that resell tyres are automatically becoming producers, and they have not assumed the corresponding responsibility for waste tyre management in Tunisia. Secondly, Tunisia does not have models for a waste tyre management system, as the EU does. Thirdly, there is no readily available data detailing the annual trading in tyres bought or number of waste tyres that enter the waste stream.

3.1. Ontological Paradigm and Epistemological Underpinning of the Study

The methodology followed in pursuit of this research study, such as the methods used to collect data and the sources contacted to obtain this data, are all closely related to the ontological and epistemological assumptions the research adopts about reality (Grix, 2004).

Historically, the two dominant ontological perspectives that have inspired social science research are positivism and interpretatism/constructivism (Robson, 1993; Guba and Lincoln, 1994; Grix, 2004). Before moving forward, it is necessary to be clear about the terminology used in this study. Constructivism is often confused with constructionism; the first refers to “the meaning-making activity of the individual mind", while the latter includes its focus on "the collective generation [and transmission] of meaning" (Crotty, 1998, p. 58). The constructivist paradigm is on occasion referred to as interpretivism (Chen et al., 2011).

These terms are often used interchangeably (Mertens, 1998; Creswell and Poth 2017). In order to avoid further confusion, this study will refer to the constructivist/interpretivist paradigm as constructivism.

Linked to the ontological position of objectivism, it is important to acknowledge the epistemological perspective of positivism, in which actors argue that reality exists independently of our knowledge of it (Grix, 2004) and who consider the social world to be something that has been revealed to us, not constructed by us (Miller and Brewer, 2003). From the positivist position, it is concluded that "objective knowledge" is possible, because there is a constant and unchanging reality that can be accessed and researched with precision. Positivism, therefore, supports the application of methods and practices of natural sciences in social sciences (Denscombe, 2002). Thus, the essential characteristic of positivism is the claim that methods, concepts and procedural rules of natural sciences should be or can be applied to the study of social phenomena (Bryman, 2001; Grix, 2004; see figure 3.1). Therefore, the essential characteristic of positivism is the claim that methods, concepts and procedural rules of the natural sciences should be or can be applied to the study of social phenomena (Bryman, 2001; Grix, 2004). The epistemological assumption that follows from positivism is that in a world known to us through our sensory experience, people simply receive sensory stimuli and recount the response, and thus contribute to knowledge (Miller and Brewer, 2003). Positivist thinking, therefore, depends for its accentuation or refutation of theory on data revealed from or collected by the way the world is observed and experienced through our senses - in this case, "objective, official statistics" (Miller and Brewer, 2003).

Data for the positivist model of social research are called “hard data”, which means that they are untainted by the interpretative and conceptual processes of the researcher or the researched (Creswell, 2003) and as such, these positivist data are numbers which seek to measure and describe social phenomena by the attribution of quantification (Miller and Brewer, 2003). Therefore, this gives a selective affinity between the natural science model of social research and those data collection techniques which give the best access to sense-experience data. These techniques include in particular questionnaires, social surveys, and experiments that generate numerical data and are supposed to make social phenomena" objective ", untouched by people’s interpretative and reality-constructing capacities (Miller and Brewer, 2003).

Contrary to the positivist view of social reality and how it can be known, the perspectivism epistemology considers reality to be a complex social construction of meanings, values and lived experience (Cohen et al., 2000; Grix, 2004) thus, it can best be understood by people's interpretive or meaningful abilities rather than by our sensory observation and experience of the world, as positivists believe (Robson, 1993; Bryman, 2004).

The epistemological position of constructivism is transactional/subjectivist, suggesting that the researcher develops the understanding from participants' views of a phenomenon (Denzin & Lincoln, 2008), that findings are created (Guba & Lincoln, 1994) and that the researcher is attached to the subject of the research. According to Creswell (2007), the aim of interpretivist/constructivist research is to rely as much as possible on participants' perspectives of the phenomenon. Therefore, constructivist researchers attempt to interpret the world in terms of participant's divergent perceptions and experiences. Thus, they employ participants' points of view to investigate the meanings of phenomena (Morrison, 2007).

Data in this interpretivist/constructivist research can be obtained from the interpretations provided by people of their real-life situations and experiences. Often referred to as "soft data," these data are often verbal and seek to detect and describe social phenomena by the attribution of words (Grix, 2004; Bryman, 2004). Interpretive/constructivist research, therefore, differs from the positivist or natural science model of investigation and uses research methods and data collection techniques that allow research subjects to interpret their own experiences of the world, rather than those uses in positivist studies. Whereas the interpretivist/constructivists do not generally begin with a theory (as with positivist research), rather they develop a pattern of meanings inductively throughout the research process (Creswell, 2003).

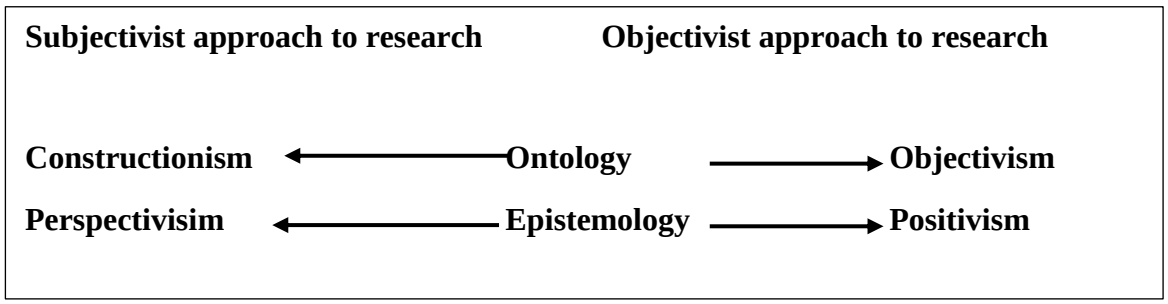
Thus, interpretivist/contructivist research relies heavily on qualitative data, but can sometimes benefit from including quantitative data as well. Sometimes, the joint use (combination) of qualitative and quantitative data may help generate unique insight into a complex social phenomenon that is not available from either types of data alone (Mackenzie & Knipe, 2006). Interpretivist data collection techniques include observations, interviews, audio-visual materials and documents which generate data mostly in the form of words that express opinions or describe perceptions (Creswell, 2003; Creswell et al., 2003; Bryman, 2012).

Due to the qualitative nature of this research, words are used predominantly in collecting data; enabling people to provide their opinion on the subject matter related to waste tyre management in Tunisia, as opposed to relying on abstract numbers. Drawing on an inductive, interpretivist/constructivist approach to the language-based data generated by the interview and observation data collection, while adopting a more quantitative and positivist approach to the data on tyre production and usage, obtained from secondary sources.

Accordingly, the philosophy stance of this research relies on the constructivist ontology in terms of an approach that:

- Listens to lots of different views
- Weighs examples – government might give different reasons for tyre waste than garage owners and an epistemology position that adopts perspectivism in terms of:
- Techniques designed to take into account of many different views
- Perspectivism – conveys the idea that all knowledge is conditioned by the perspective of the knower (Silverman, 2010). Figure 3.1 illustrates the contrasting 'modes of research'.

Figure 3.1 Basic Outline of the Contrasting 'Modes of Research' (adapted from Woods, 2011, p. 107).



3.2. Qualitative and Quantitative Approaches

Some research methodologists believe that the contrasts between positivism and interpretivism are significant because adhering to one of these ontological positions will drive a researcher to utilise a different epistemological approach and research methodology than if they were to adhere to the other, and that a researcher's epistemological position can lead to different perspectives of the same social phenomena (Robson, 1993: Denscombe, 2002).

The ontological (the study of existence) distinction between positivism and interpretivism has generated epistemic distinctions between qualitative and quantitative research visions. In social science research, quantitative research typically rests upon the assumptions of

positivism, whereas qualitative research relies on an interpretivist assumption (Bryman, 2001; Denscombe, 2002).

The starting point of quantitative social research, as the name implies, is numerical measurement of social phenomena (Bryman, 2004; Grix, 2004). Scientists or researchers who utilize the quantitative approach for the most part utilize a systematic approach in which competing explanations are created in terms of relationships between variables (Grix, 2004). In this way, quantitative researchers more often than condense what they study into various key attributes which are commonly taken as pointers or variables (Miller and Brewer, 2003).

A definitive goal of quantitative research, as Miller and Boyer (2003: 193) have stated, is "to find as small a set of variables as possible that explain as much as possible" and the more extensive philosophical reasoning that guides the approach is, to know something, one has to create general sets of strong relationships across as many instances as possible (Miller and Brewer, 2003).

Generalization is, consequently, the objective and the fundamental motivation behind why the researcher is keen on building up relationships to demonstrate that these are general highlights and or features of social life (Ragin and Becker, 1998; Miller and Brewer, 2003; Grix, 2004). Along these lines, this sort of approach is appropriate to testing theories, distinguishing general patterns and making expectations (Ragin and Becker, 1998). The quantitative approach is, in this manner, deductive in nature and connected with positivism and the natural science paradigm of investigation (Miller and Brewer, 2003).

Conversely, qualitative research is seen by many as a nearly the direct opposite of quantitative research. As a rule, qualitative researchers give their attention to work in the interpretivist/ constructivist philosophical tradition, utilizing methods of gathering data that are sensitive and flexible to the social context in which the data and information are being produced (Grix, 2004). The qualitative approach usually involves in-depth investigation of a specific social context or phenomena via such means as participant observation, interviewing, archival or other documentary analysis or ethnographic study, in addition to methods which do not rely on, but can involve numerical measurements (Ragin, 1994). In accordance with the interpretivist/constructivist paradigm, qualitative researchers for the most part look to gather data from their studies on event, institution or geographical area, with the goal of establishing patterns, directions, trends and relationships between variables (Grix, 2004). The language of qualitative research in general revolves around investigations

related to case-studies and social contexts rather than variables and hypotheses, as are employed in quantitative research. As expressed by Holloway (1997, p.80) "qualitative research involves the interpretation of data whereby the investigators analyse cases in their social and cultural context over a specified time period" and may inductively develop a theory or pattern of meanings through the research process (Creswell, 2003).

Some scientists take extraordinary positions on the relative benefits of qualitative and quantitative approaches in the research of the social science (Preece, 2000). A key argument against qualitative research is that it is ordinarily small-scale and non-representative, producing results that cannot be generalized beyond the cases investigated (Grix, 2004). This means 'the state of being unable to generalize' from small samples or limited cases compromises the authenticity of results gained via qualitative research. Moreover, in the perspective of pundits, immersion of researchers in the social setting they study leads to an absence or a lack of objectivity and a propensity to utilize closely-held convictions (personal opinions) instead of evidence to help and support arguments (Preece, 2000). Consequently, qualitative research is frequently indicted for being unscientific, unrepresentative, open to bias and even to fraudulence and manipulation, regardless of whether this is cognizant or oblivious (Grix, 2004; Bryman, 2004).

Despite its reputation, quantitative research has been criticized for many reasons. One such criticism is that researchers working within the quantitative tradition are often hesitant to move from correlation of data to establishing causal connections between data and this can influence comprehension of the social situations being investigated (Silverman, 2000). As indicated by Preece (2000), a quantitative approach can likewise be condemned as reductionist, since it uses pre-conceived or incomprehensible concepts, and therefore, is prone to bias or manipulation and/ or fraudulence in a different way. Besides, excessive reliance on quantitative methods can neglect the social and cultural context in which the variable being measured exists (Grix, 2004). Critics also argue that quantitative research is not devoid of value judgements, as some of its proponents suggest, because no one can be completely separated from any type of research (Silverman, 2000; Grix, 2004). Furthermore, numerical measurement, which are crucial in quantitative research, are difficult to collect when it comes to certain aspects of human interaction such as behavioural phenomena (Bryman, 2004; Grix, 2004). Thus, practitioners on every aspect of the methodological gap accuse their opponents of a deformation of the truth. While such conflict is often useful in

highlighting principles, there is usually considerable value in accommodation between approaches.

3.3. Combining the Two Methodologies

Following the qualitative and quantitative discussion, the question remains whether the two contradicting approaches could be usefully combined in one study. From the perspective of Blaikie (2000), triangulation or the combination of methods is actually difficult because of the difference in epistemological and ontological underpinnings of the two research strategies. Authors such as Lincoln and Guba (1985), Hughes (1999) and Blaikie (2000) oppose the idea of combining the two research strategies into one study for the reason that research methods carry epistemological obligations, and the use of any data collection technique is not just an issue of gathering data, but it is an obligation to adopt either positivism or interpretivism (Blaikie, 2000; Grix, 2004). This implies that qualitative and quantitative research are based on two incompatible epistemological principles. According to Lincoln and Guba (1985), the combination of the two approaches is improper and represents a 'failure' to perceive the differentiation between model and method. They debate that use of any data collection technique implies adherence to the approach with which it is usually associated and this makes the combination of the methods inappropriate.

In contrast to the above position, several authors heavily underscore the feasibility of combining the two approaches, despite their disparate epistemological underpinnings (Grix, 2004; Bryman, 2004). Breman (2004) argues, for example, that the methods themselves should be seen as mere instruments for gathering data and should not be seen as automatically rooted in epistemological and ontological obligations. Therefore, he believes that the research methods from one strategy are able to contribute into the service of another (Bryman, 2004).

To support this position, several scientists of research methodologies recognise that there is much that can be gained from combining qualitative and quantitative methods into one study of social phenomena (Denzin, 1989; Robson, 1993; Creswell, 2003; Grix, 2004). For example, Denzin (1989) suggested that triangulation might be done in social research by utilising a variety of techniques, methods, sources, investigators, or theories, while Robson (1993) also observes that a social research query/question can, in most cases, be addressed by more than one method. As indicated by Robson, there is no standard that says exclusively one method must be utilized for an investigation in the research. He proceeds to support that

utilising more than one method in single research can have significant advantages, even though it is certain to happen 'inevitably'. In this regard, many other scholars support this approach, such as Preece (2000), who observed that there are several disciplines that can be connected effectively with mixed methods (qualitative or quantitative), in which both find a place in most fields of study.

The perspectives of these scholars suggest that the strategies of combining qualitative and quantitative approaches can complement each other in one study of social phenomena. As stated by Grix (2004, p.84), "as long as you are aware of how you are utilizing a specific method, how it guides you, and how this relates to the ways you use other methods, there should be no problem". In this regard, Grix (2004) provides an opinion about what could or should be done about a situation of utilizing mixed methods by advising that it is generally a good idea for social scientists to utilize more than one research method, to improve the chances of obtaining better, more reliable data and to reduce the chances of biased results. He argues, for instance, that there is no reason why a researcher cannot utilize methods that are usually connected with quantitative research in an in-depth investigation. These arguments provide a consistent base for combining qualitative and quantitative methods in the investigations of social science. Thus, despite the criticism, the strategy of mixed methods of social investigation quickly became popular among scientists and researchers (Grix, 2004; Bryman, 2004).

3.4. Methodological Approach

As stated in Chapter 1, the purpose of this study is to investigate waste tyre management practice as an aspect of solid waste in Tunisia, in order to understand the nature and causes of the tyre waste problem and environmental issues associated with this waste stream. The diverse nature of the data required and the various sources collected from them make the mixed approach appropriate. In accordance with this methodological approach, research instruments associated with both qualitative and quantitative data collection approaches were combined, comprising interviews, field observations and documentary analysis.

The decision of choosing the mixed methods approach was informed by various arguments. Firstly, it was intended to achieve the rationale of triangulation (Denzin, 1989) because no single method, could totally catch all the important highlighted and relevant features of the study. Moreover, the combination of qualitative and quantitative methods allowed the researcher to crosscheck the data collected by various techniques, making the results of the

study more valid and reliable. As Bryman (2004, p.131) noted, "the combination of different methodologies in one single study reinforces the researcher's claim that his conclusions/findings are valid if they can be proved to provide mutual affirmation".

In addition, the decision to combine two methods (qualitative and quantitative) in this study can also be justified on the basis that it enabled me to explore much information from various perspectives that may lead to a broader understanding of the issues associated with tyre waste management in Great Tunis. In this regards, Bryman (2004) argued that while quantitative research is connected to a researcher's point of view, qualitative research is concerned with seeing the subject matter of study through the eyes of the participants being studied. Along these lines, the combination of qualitative and quantitative methods in this research study made it possible to accommodate issues related to tyre waste management in Tunisia from the perspectives of major participants that represent stakeholders in the waste sector, as well as from the researcher's own point of view (observation data). Moreover, the combination of various methods of data collection and analysis provided me with alternatives: on the one hand, the qualitative approach enabled me to obtain in-depth information from different categories of participants, including providers of waste disposal services, public institutions, those are involved in waste management in one way or another, tyre dealers and workers in the scrap yard that hosts scrap vehicles. This in addition to the communities hosting waste disposal facilities in the study areas and others such as civil societies active in the aspect of environment. On the other hand, a more quantitative approach allowed me to obtain data on tyre production and usage obtained from secondary sources. Thus, without this mixed-method approach, dependence on any individual approach to data collection could result in the loss of much valuable information.

3.5. Selecting Great Tunis as a Place to Study

Great Tunis is the largest urban agglomeration in Tunisia, and thus formed the subject for this study. This provided the study with an opportunity to investigate the problem of a tyre waste disposal crisis, even though the tyre waste menace was common to all Tunisian cities. The choice of this site to conduct the research was determined by both methodological and practical aspects. The main considerations in choosing the site for field research were:

- Tunis is the capital city of Tunisia. Greater Tunis region includes the states of Tunis, Ariana, Ben Arous and Manouba, which full under the city of Tunis and around (suburbs).

- More than 40% of Tunisian residents live in those cities. In addition, it has a very high percentage of residents and non-residents in terms of vehicle density.
- Tunis has a large range of industrial areas and service activities and is considered the centre of economic development, with transportation network infrastructure linking the areas together, thereby increasing the density in both passenger and commercial vehicles, making it the leading source of tyre waste generation as an aspect of solid waste.
- Tunis as capital has a wider variety of SWM technologies, and a higher number of private SWM companies may be found here than elsewhere in Tunisia.
- Great Tunis is a key location for institutions and organisation bodies, in addition to the other institutions, thereby giving the study access to decision-makers. There was the opportunity to analyse their experience in the city, as well as to clarify the actual picture of the current SWM generally, as well as focusing on the waste tyre situation in this area specifically.

3.6. Technique Sampling

Sampling is a process of choosing units (e.g., individuals, organisations) from a population of interest with the aim to drawing conclusions for the entire population after conducting a study of a sample selected from the same population (Arber, 2001; Trochim and Donnelly, 2001; Hargittai, 2015). Accordingly, there are two fundamental kinds of sampling: probability and non-probability sampling (Kitchenham and Pfleeger, 2002). The distinction between the two kinds is whether the sampling selection involves randomisation (Lepetit and Fua, 2006). Randomisation happens when all members of the sampling frame have an equivalent chance of being chosen for a study investigation (Naderifar et al., 2017; Banerjee et al., 2015). This research study was concentrated to a great extent around the key waste management stakeholders, consequently, purposive sampling (using non-probability as a technique for sampling) was utilized to acquire the data from the key stakeholders in the study area. Table 3.2 illustrates the main stakeholders for waste management in this study. Therefore, the purposive sampling technique was appropriate in this study because the NGO that cooperated with the researcher had a knowledge of the group sampled (Roy et al., 2015). At the same time, the researcher utilised the snowball sampling method. Snowball sampling is a type of purposive sampling where existing participants recruit future subjects from among their acquaintances. Thus, the sample group appears to grow like a rolling snowball until reach data saturation is achieved (Grove, 2001).

3.7. The Research Population and Sample

Taking into account the aforementioned points in the choice of Great Tunis as a site for study, the tyre waste as an aspect of the solid waste stream is usually generated in commercial centres/businesses and services such as tyre importers, local tyre traders and distributors, and garages for fix and replace tyres, and on streets as well as vehicle scrap yards. Therefore, all tyre waste generating sectors in the Great Tunis were part of the study population for this study. In addition, key stakeholders were represented in those who had frequent dealings with solid waste and tyre waste, whether supervisory, implementing or advisory, including private sectors (service providers, recyclers and informal waste collectors) that deal with solid waste in Tunis, i.e. those involved in some aspect of waste tyre. The key issue was to make sure that all stakeholders were identified so that their influence could be assessed and planned for. In this regard, the researcher collaborated with NGOs active in the field of environmental management in Tunisia in order to identify the key stakeholders in this study. The researcher conducted the initial coordination with the NGOs via Skype for four weeks in October 2015, in order to communicate with key stakeholders (via NGO) to identify who was desired to participate in this study. This enabled me an initially to familiarize myself with the key stakeholders in the waste sector, who were willing to participate in the interviews, and enabled me to pre-test the research tools (interview guides) before conducting the main interviews.

3.8. Key Stakeholders as Respondents for the Study

Respondent participants comprised those people who had information and a good understanding of the problem that needed to be explored in the course of the study. This included those groups who represented specific groups of stakeholders, who may have had a responsibility, or were active in civil society organisations, or experts in a particular field (Laforest, 2009). In order to avoid a significant bias in the responses about the extent challenges to sustainable tyre waste management, the researcher included different groups of participants in the semi-structured interviews, including the group selected from the NGOs, a group selected from the private sector in the field of trading, repairing and recycling tyres, and the last group selected from those institutionally responsible for SWM. Semi-structured interviews have the advantage of affording the opportunity for exploring attitudes and values, as well as the motives and beliefs of each participant. In addition, this method is useful for discussing sensitive issues that needed in-depth information (Barriball & While, 1994).

Table 3.2 Key Stakeholder Respondents to the Interview

Category of main stakeholders	**Actual participants selected for study**	**Position**
Public institutions with functions affecting solid waste management	• Ministry of Environment and Sustainable Development (MESD) • National Environmental Protection Agency (ANPE) • Tunis International Centre for Environmental Technologies (CITET) • National Agency for Waste Management **(**ANGED)	• Senior official at The General Directorate of the Environment and the Quality of Life • Engineer affiliate to Department of Environmental Assessment and Remediation Assistant Director of International Cooperation • A head of Waste Management Department and two other officials
• Public institution related to driving licenses, vehicle registration, technical inspection, preview, acceptance and authentication.	• Technical Agency of Terrestrial Transport (ATTT) affiliate to Ministry of Transportation	• An official at the Technical Agency for Land Transport
Research institution	• The Water Research and Technologies Centre (CERTE)	• Research and Advisory
Producers of waste tyres for disposal	• Tyre importer, • local tyre traders and distributors, • garages and shops for repairing and replacement of new tyres, • scrapyard of vehicle (Dealer)	In this category, part of the participants represented the owners and the other part, the workers
Providers of waste disposal service	• Al Zahra Municipal Council • Informal waste collectors; • landfill	• Former Member • Scavenger
Non-government organisation (NGO)	• Tunisian Organisation for Consumer Information (TOCI) • Environment and Heritage Society (EHS)	• Founder and member • Members (Engineers)

Therefore, the researcher conducted fieldwork and identified participants willing to respond. The key stakeholders who responded and participated in this interview represented various groups, namely: Tunisian national and local authorities; Ministry of Environment and

Sustainable Development, National Environment Protection Agency, Tunis International Centre for Environmental Technologies, National Agency for Waste Management, The Water Technologies Research Centre, and a former member of Al Zahra Municipal Council. Meanwhile, the private sector was represented by: Tyre importers, local tyre traders and distributors, garages and shops for repairing and replacement of new tyres, vehicle scrapyards, as well as informal waste collectors and landfill services. In addition, the major contributing NGOs were the Tunisian Organisation for Consumer Information, and the Environment & Heritage Society, as shown in Table 3.2.

3.8.1. Public and research institutions and Municipal Council

For public and research institutions (MESD, ANPE, CITET, ANGED, CERTE, ATTT), interviews with some officials had a good impact on providing appropriate answers to the interview questions. In all the institutions visited, the researcher attempted to develop a close and harmonious relationship, as well as using humility to induce participants to grant interviews. Here, the introduction letter written by the researcher and revised by supervisors was very useful. In this regard, two officials from the National Agency for Waste Management (ANGED) (Head of Waste Management Department and another official) participated in formal and informal discussions. One other official was interviewed at the Plastic Collection Centre (ECOLEF) affiliated to the ANGED. With regard to the other public and research institutions (MESD, ANPE, CITET, CERTE and the ATTT), one official was selected from each of those institutions, in addition to a former member of Al Zahra Municipal Council. Thus, seven officials were from public institutions and one from a research institution, while the other one was from a Municipal Council involved in the interviews; i.e. a total of nine from different institutions.

3.8.2. Producers of Waste Tyre Disposal

The aim to interviewing participants from this disparate renege of groups was to evaluate practices in terms of production, storage and disposal of waste tyres. This involved interviewing participants from three different types of tyre waste producers: tyre importers; local tyre traders and distributors; garages and shops for repairing and replacement of new tyres; vehicle scrapyards. In spite of using a systematic technique to select those participants, on occasion it was not possible to obtain as much information as expected from these participants, because some of them were unskilled workers who did not have sufficient knowledge pertaining to the questions asked. In this case, the researcher used snowball

sampling in order to find the business owners who managed less knowledgeable participants to gain as much information as possible. Usually, business owners are familiar with the legislation and policies that are relevant to their business and affect their approach to SWM. Thus, the size of the samples of this interview became thirteen participants, representing three different groups.

3.8.3. Participants from NGOs

Despite rapid economic and technological evolution, today humankind faces various complex socio-environmental issues such as urban sprawl, waste disposal, warming, acid rain, air pollution, and many more issues that affect every human, animal and nation on this planet (Sarkis et al., 2010). The scope and complexity of these issues drives organizations from different sectors to convene multiple partners from different sectors: such organizations are known as NGOs, and generally comprise scientists and community advocates to explore innovative solutions that effectively address problems that span national and international concerns (Sarkis et al., 2010; Lin, 2012). Therefrom, the researcher included participants from NGOs as an important part of this study. Lempert and Nguyen (2008) expressed that Non-governmental organizations (NGOs) have become a key player in dealing with many economic, environmental, and social development issues. Consequently, conducting interviews with the NGOs played a major role in providing the researcher with information and a deeper understanding of the environmental issues and challenges facing Tunisia in the contexts of waste management. Thus, two-members from each NGO were involved in this interview, i.e. a total of four from two different NGOs.

3.8.4. Private Informal Waste Collectors

Finding informal tyre waste collectors was very difficult, contrary to expectations. Despite the use of snowball sampling only one participant was found who agreed to conduct an interview, but by phone. (This participant worked for Ecobeno recycling company). The other participant (waste picker) was found by chance in the field of plastic waste collection, because informal waste collectors were not confined to any particular place in the city. Thus, no methodology could be used to determine who would be interviewed. With regards to the participant recruited by accident, in spite of his specialism in plastic waste collection, the researcher approached him and introduced the study and asked him to grant a short interview in order to obtain more knowledge and information as an informal worker involved in picking waste. Regarding the participant that I had interviewed by telephone, I tried to use a

snowball technique to find other participants, but this was not helpful because tyre waste collectors were working individually and in most cases did not know where others worked.

3.9. Methods of Collection Data

After carefully considering the research objectives, the nature of the data required for the analysis and the predominant conditions in the field of the research, it became apparent that the most ideal approach to gather satisfactory data for the research would be a combination of the methods of both qualitative and quantitative approaches. This is on the grounds that the greatest portion of the data required was qualitative in nature and could best be acquired through interviews, while others were quantitative and accordingly, could be obtained from secondary sources (e.g. statistical data for tyre production). Moreover, parts of the data were physically observable and could be collected through direct field observation. There was likewise a range of published information such as newspaper articles, reference books, academic journals, and other publications that could yield valuable and useful information for the research study. Taking this perspective into account, the researcher ended up persuaded of the usefulness of combining two different methods, namely both qualitative and quantitative approaches, in my endeavour to collect the data required for this research study. Therefore, the study used interviews, field observation, documentary analysis and secondary data sources, drawing on the strengths of combining methods to improve the quality and validity of the data.

3.9.1. Interviews

Interviewing is one of way to collect valuable and useful data from people who have relevant experience and knowledge, through a one-to-one verbal exchange between the researcher and interviewee (Hay, 2005). The interview technique is considered as more useful because most people are more willing to talk in an interview than the case would be in the event that they were asked to write responses or fill out a questionnaire (Robson, 1993). In addition, this technique is useful because it is 'introspective' and allows participants to report on themselves, their views, practices, beliefs, interactions and concerns (Freebody, 2003). The interviewer attempts to elicit information from persons by asking predetermined questions (Longhurst., 2010). In this regard, Barriball and While (1994) argue that the formulation and sequence of all questions directed in standardised interviews are exactly the same, and hence the difference in answers is not the result of a difference in questions, it is a result of the difference in the perspectives of participants involved in the interview. Consequently,

Denzin (1989) clarifies that a semi-structured interview affords the interviewer the opportunity to change the words but not the meaning of the questions provided, which acknowledges that not each word has the same meaning to each participant and not each participant will utilise the same vocabulary. Therefore, in this type of interview, the validity and reliability depends not upon the repeated use of the same words in each question, but upon a parity in the transfer of meaning. Therefore, one of the advantages of the interview technique it creating the opportunity for interviewees to ask for clarification when they do not understand a question, just as the interviewer can ask for clarification or elaboration about the answers that the interviewee provides. Thus, there is a surety that all questions will be answered or, at least, there will be an attempt at an answer by the person interviewed (once he/she can permit sufficient time for the interview), which secures a high response rate (Freebody, 2003). The purpose of conducting interviews was to obtain data from a number of stakeholder groups in the study. These were:

- Officials of public and research institutions (MESD, ANPE, CITET, ANGED, CERTE).
- A former official of the Al Zahra municipal council.
- Business owners /operators and staff of the private sector.

3.9.1.1. Developing Interview Guides

Adequate preparations were made prior to my interview with the interviewees. In doing so, I was guided by Laforest's advice (2009) on the use of the interview technique of data collection. These include:

- Devise the interview plan in terms of establishing the interview structure according to the research questions, and deciding which questions are appropriate for the participant.
- Avoid vague questions that have more than one concept or dual concepts.
- Develop a consent form specifically for the participant in which the interview rules in terms of commitment and anonymity are made explicit.
- Explain the goal of the interview, clearly identifying the interview topics or themes.
- Obtain permission from the participant.
- Obtain agreement on the date and place of the interview, which should be comfortable, quiet, and easy to access.
- Decide and prepare the mode for recording the interview (note-taking, tape recording, or both).

Based on the specific objectives of the study and guided by Laforest's (2009) advice, interview schedules were developed for each of the different groups of participants (as listed

above) in order to address issues related specifically to their respective roles in tyre waste management. In all cases, the interview schedules were semi-structured, which allowed the respondents some latitude to follow what they considered relevant while making sure that key questions were sufficiently answered.

The interview schedule for the main stakeholders, i.e. those representing public and research institutions (MESD, ANPE, CITET, ANGED, and CERTE) as well as Al Zahra municipal council and NGOs (Appendix 3.1), was the most detailed and covered a range of themes that dealt with the various issues in waste management. The themes which were covered by the questions included: stakeholders in the waste sector; the tyre waste situation in the cities; resources for waste management; funding system for waste management; constraints on participation. At the same time, separate interview schedules were also designed for the private sector, (namely the tyre importer; local tyre traders and distributors; garages and shops for repairing and replacement of new tyres; vehicle scrapyards). These schedules were simple but covered relevant issues relating to waste tyres that enter the end-of-life cycle after being brought to garages for repair or replacement with new tyres. Interviews covered the current practices with regard to this waste, as well as the policies and regulations that were in place (Appendix 3.2). Interview schedules were also designed for discussions with a sample of informal waste collectors. With the informal waste collectors, the issues discussed included the nature of their work, clientele for their services and how they perceived their role towards other service providers in the organisation of waste management (Appendix 3.3).

3.9.1.2. Assuring the Validity and Reliability of the Interview Guide

According to Patton (1990), the validity and reliability of qualitative data are highly dependent on the interviewer because he or she expects to be the central character in the interview session. The interviewer plays a vital part in facilitating the interview session by ensuring the interviewees understand the questions posed while also obtaining the evidence needed to answer the study questions. In this regards, care was taken by the researcher to ensure that the interview schedule was valid and reliable. As a matter of first importance, the themes on which the interview questions were placed were drawn from the study's specific objectives. After the interview guide was developed, a copy was given to two research students (who utilized the interviews in their own research) in order to review it and comment on its contents. After feedback amendment recommended by the researcher students, it was then given to my supervisors who gave me useful advice for more

improvement. After that, the interview schedule was translated into the Arabic Language and then was sent to NGO who cooperated with the researcher as an instrument to test it with participants from NGO members, which showed that the content of questions was easily understood. The pilot responses that obtained from NGO participants were compared with the objective of the study, which became evident that the interview schedule was trustworthy as it generated the right type of data the fulfil the objective of study. However, there are a few inadequacies were specified in the design. These included the ordering of themes and questions in some of the interview schedules and the repetition of some issues in some questions. These were corrected in order to improve the quality of the test instrument before utilised it in the fundamental fieldwork.

3.9.1.3. Conducting the Interviews

It is necessary to note initially that all interviews conducted with participants in Tunisia used the Arabic language to facilitate the process of communication and ease expression for the participants. Barriball and While (1994) indicated that interviews with participants whose native language is not English mean the interviewer must be aware of the use of words in terms of validity and reliability of data. Recognising the challenges involved in translating interviews (Coteerill and Letherby, 1994; Burgess, 2002), the researcher made sufficient preparations and effort to maximize the likelihood of successful interviews. The researcher started by writing to the main stakeholders (i.e. Al Zahra municipal council, public and research institutions, and business man owners of tyre brand names) informing them of my studies and request them to participate in interviews (Appendix 3.4). An introduction letter was sent to the potential interviewees, with an interview schedule to inform them about the issue to be covered during the interview. This form also collected the names of their institution/organisations, their rank or title and their telephone/email number to contact them. After that, the researcher contacted participants to arrange a preferred date, time and venue for the interview. One day before each appointment, the researcher made phone calls to remind participants of our meeting and to confirm whether they were able to keep to the appointment. Those who apologised for not attending the meeting (there were many of them) were rescheduled for later dates and times (in some cases several times).

The interviews were mostly conducted in participants' workplaces, while some preferred interviews in a public place. At the beginning of the meeting the researcher reiterated the purpose of the meeting and reminded the participant that the interview was for research purposes only and assured him/her of confidentiality and anonymity in the use of the

information he/she was going to provide. After this, the researcher indicated that he would like to audio record the interview after gaining permission from the participant. On occasion, the interviewee objected to an audio recording. In this case, the researcher resorted to writing the responses in note form, with the aid of the NGO member using the transcript of the interview schedule. Interview duration varied, depending on the interaction with the interviewee. Generally, the researcher spent one hour and a half to two hours with each participant when conducting an interview.

At the end of the interview, the researcher thanked the participant and asked if they would like to read and check the transcript of the interview for validation. However, many of respondents said this was not necessary, but others participants were happy to validate their interview. The interviews with non-elite participants such as (workers), informal waste collectors or vehicle scrapyard operators did not need detailed preparation beyond the design of the interview schedules. In this regards, the researcher always made initial visits and talked with many people in order to familiarise himself the research field. After this, the researcher was able to interview some of them during the first attempt, but some of the other interviews had to be pre-arranged. The other interviews, especially those with the owners of tyre distributors and importers, were arranged and confirmed beforehand. Throughout the interviews, the researcher made great efforts to maximise the data obtained from the participants.

The researcher also applied observation during interviewing. The researcher often thinks he controls the interview, but interviewing elites is a different experience because they often feel they have power over you and the researcher is aware of it. During one of the researcher's interviews with a government official, the researcher was aware of his lack of control of the situation, making it difficult to obtain some answers I needed. For instance, some of the government officials interviewed insisted that their voice was not recorded in spite assurance of confidentiality. It was therefore impossible to capture all of what they said on paper when they were speaking due to the need to write notes and conduct the interview. This led to the loss of some information, but the researcher succeeded to fill this gap of information later because there was a collaborator accompanying the researcher who assisted in taking notes the interview. Thus, the researcher faced some limitations despite the advantages of interview technique in terms of gathering data. In general, the interviews were successful in generating data for analysis of the issues involved in the study.

3.9.1.4. Validation of the Interview Data

It is important for researchers to review and check the interpretations of interview data with respondent participants to guarantee its reliability. While giving credibility to what people are saying, the researcher should develop and maintain a decisive attitude towards what the participants tell him/her. Thus, steps were taken to validate the interview data gathered from the participants.

To verify the validity of the interview data obtained from the waste tyre producers in Great Tunis, the transcripts of the interview were subsequently presented to the interviewees for comment. The few changes they suggested before the data were used for analysis were internalized. Moreover, the information given by official staff of the National Agency for Waste Management were compared with what other stakeholders; for example, with the municipal council mainly responsible for the management of waste collection, and vice versa. In a few cases, there were discrepancies, so the participants were contacted for explanation, clarification and correction before the data were completed for use in the study. Bowen (2009) noted that the use of triangulation in a qualitative approach, such as secondary data sources besides interviews and observations, provides a set of evidence that generates credibility. Thus, the researcher supported the data obtained from the respondents by using documentary sources such as government reports, official records and newspaper articles available.

3.9.2. Field Observations

According to Taylor-Powell and Steele (1996), observations are a form of evidence that can give unique information that does not rely on verbal behaviour and the method enables the researcher to observe the phenomenon under study directly. Miller and Brewer (2003) and Kawulich (2005) have classified observation into ‘participant observation’ and ‘unobtrusive observation’, based on the degree of involvement of the researcher, and into ‘covert’ and ‘overt’ observations based on the level of awareness of the subjects being observed.

Due to its appearance in many public places in greater Tunis, the phenomenon under study, tyre waste as an aspect of solid waste, is one that allows for direct field observation. Thus, in addition to interviews, field observation (unobtrusive observation) was also conducted as part of the data collection exercise. This included observation of tyre waste cases and other conditions that could affect waste management in study areas. Waste tyre management practice was observed to collect data on such issues as environmental quality of surrounding

or nearby business activities (mainly in the area of tyre importers, local tyre traders and distributors, garages and shops for repairing and replacement of new tyres, and vehicle scrapyards). The researcher visually assessed the waste disposal sites in terms of the standard of maintenance and environmental quality surrounding it. The researcher used a checklist (Appendix 3.5) during field observation that consisted of a set of questions to observe the performance and behaviour practices of the waste tyres management in the community at unofficial landfills and garages, distributors, importers of tyres and vehicle scrapyards.

During field observation (unobtrusive observation), some photographs of tyre waste scenes were taken by the researcher in streets, near storage containers, in the open spaces between residential neighbourhoods, and open space near to tyre business activities in a different area located in Sakra, Bab Alkhadra, Borj Cedria Hay Al-Sultan, El Yahoudia, Chadli Guellala Avenue Belvédère and Manouba. Some photographs were prompted at the vehicle scrapyard by how the waste tyres were stored randomly. The researcher also participated as a 'participant observer' with tyre repair technicians (after informing them of the research project) in their workplace in some parts of Great Tunis to gather data on their practices and attitudes toward waste tyres. Some photographs were taken (after gaining owners' consent) of tyre waste scenes in terms of storage, transportation and final disposal.

The exercise allowed me to gain first-hand knowledge of the tyre waste situation in Great Tunis, including the tyre waste disposal habits of the producers and the level of tyre waste disposal services available to them in Great Tunis. Field observations conducted to collect data for this study were for most part unobtrusive. The situations observed were often waste tyres scenes, such as tyre waste in streets, near storage containers, in the open spaces between residential neighbourhoods, and open spaces nearby to the business activities for tyres and disposal sites. The observations were conducted in a manner that did not attract the attention of the people around. Also, the other part of observations (which can be referred to as participant observation) covered the practice of tyre producers' activities in their premises to notice their practice and attitude toward the tyre waste they were generating. Indeed, it can be said that field observations covered all four categories identified by Miller and Brewer (2003) and Kawulich (2005) - involving both the cooperation of participants and unobtrusive observation; and were both covert and overt in nature. Field observations were utilised to compare the actual tyre waste situation in cities of Great Tunis with information collected through interviews and secondary data sources.

3.9.3. Secondary Data

Secondary data are those that have already been collected by someone other than the researcher, such as individuals or organisations that have not experienced directly or do not participate in the events of the particular research study (Montello and Sutton, 2006). Secondary data provides an alternative to gathering primary data (Vartanian, 2010). Secondary data is mostly collected through many sources, such as government departments (official reports, legal documents and statistical sources), university/college records, journal publications, authors' websites, self-reports (Koziol and Arthur, 2011), in addition to documentary sources that include periodicals, newspaper articles, radio and electronic media (Finnegan, 1996; Miller and Brewer, 2003). Secondary data sources were used in this study in several chapters. The review of literature, official reports, legal documents, journal publications, authors' websites and self-reports were intended to identify what is already known in the subject area (Walsh and Downe, 2005). Therefore, the researcher used these sources to provide information related to several aspects of the waste tyre management.

Table 3.3 Documents and Electronic Media Sources used by the Researcher following Interviews with Stakeholders

Documents, Articles and reports	**Key information acquired**
Mahjoub, O., Jemai, A., & Haddaoui, I. (2020). Waste Management in Tunisia—What Could the Past Bring to the Future?. In *Waste Management in MENA Regions* (pp. 35-69). Springer, Cham.	Provide useful information about the initiatives undertaken in the framework of national and international programs, and what facing sector of waste management in terms of obstacles to be urgently addressed.
Dridi, C., & Khraief, N. (2011, June). Mitigating Industrial Solid Waste in Tunisia: Landfill Use Vs. Recycling. In *Economic Research Forum Working Papers* (No. 590).	Information in the Tunisian legislation on the management of solid waste and assesses the effectiveness of economic instruments in controlling its generation.
GIZ and SWEEP-Net. (2010 & 2014). "Country Report on the Solid Waste Management in Tunisia." German Corporation for International Cooperation [Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)] and Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries (SWEEP-Net), on behalf of the German Federal Ministry for Economic Cooperation and Development [Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ)]. https://www.retech-germany.net/fileadmin/retech/05_mediathek/laenderinformationen/Tunesien_laenderprofile_sweep_net.pdf	This report carried out for the account of SWEEP-Net/GIZ to Tunisia benefit related to SWM. This report encompasses all stakeholders involved in waste management and illustrates the main environmental indicators. It also shows a common observation concerning the non-compliance of collection regulations by the citizens as well as by the municipalities.
Chaabane, W., Nassour, A., & Nelles, M. (2018). Solid waste management key indicator development for hotels: A Tunisian case study analysis. *Recycling*, *3*(4), 56.	This article provides suitable technical, organizational, financial, legal, and social indicators for SWM systems that can be used to diagnose the current situation in Tunisia.

Loschi, C. (2019). Local mobilisations and the formation of environmental networks in a democratizing Tunisia. *Social Movement Studies*, *18*(1), 93-112.	This study examines the environmental protests that occurred in Tunisia after the 2011 uprisings. It provides analyses of the factors underpinning the rise of the environmental networks during the period of transition (2011–2014). It gives the details of the mobilising strategies about the environment and pollution that were crucial for the networks' (social and political actors) growth or survival during this period of institutional instability.
Scheinberg, A., & Savain, R. (2015). Valuing informal integration: Inclusive recycling in North Africa and the Middle East. *German Corporation for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit*.	Provides an overview of the challenges of how to integrate Barbechas in post-revolutionary Tunisia. Gives information on solid waste and recycling in Tunisia context, and the issues that face the informal recycling sector in Tunisia.
UNEP, M. (2014). Horizon 2020 Mediterranean report: toward shared environmental information systems.	This report provides an overview of Tunisia's endeavours in the environmental field and provides the present evaluation based on sustainable development indicators in order to enable Tunisia to concentrate on three priority issue,s which are: urban waste, water and industrial emissions
Ayadi, L. (2015). Chambre Syndicale Nationale des Grossistes Importateurs de Pneumatiques.	Useful information by this study about the tyre trade in Tunisia, which is characterized by strong market dominance by the informal sector in proportions that far exceed acceptable tolerances. The legal trade in tyres in Tunisia faces two problems, namely tariff barriers with an import tax pressure that reaches 94% and non-tariff barriers by subjecting each customs clearance operation to the production of an authorization. In addition, this study suggests how to eradicate informal trade or contain it to acceptable proportions; the study recommends lowering the tax burden on imports and removing all non-tariff barriers.
Ayadi, Lotfi, Nancy Benjamin, Sami Bensassi, and Gaël Raballand. *Estimating informal trade across Tunisia's land borders*. The World Bank, 2013.	This paper provides information in the field to estimate the magnitude of Tunisia's informal trade with Libya and Algeria. In addition, it illustrates the scale of this trade and evaluates the amount lost in taxes and duties and how this is reflected on the local impact in terms of income generation.
Hussein and Rahu, (2015). Regional workshop on hazardous waste management methods and technologies and especially in light of the Tunisian experience. Environmental rehabilitation for institutions: tools, methods and systems	Gives information concerning challenges facing Tunisian institutions in terms of services that respect the environment, and specify the specifications and environmental requirements.
The national report on the state of the environment for the years 2012-2013 http://www.environnement.gov.tn/index.php/fr/indicateurs-et-reporting/etats-de-l-environnement-national-et-regional	This national report reflects the state of the environment for the years 2012/2013 which is sought to present, as clearly as possible, the main environmental problems that Tunisia is experiencing, which could not be overlooked in the form of a sustainable endeavour such as the investigation.

Useful links to Tunisian sites providing national and local reports

- **Environmental sites**
  - Ministry of Local Affairs of the Environment http://www.environnement.gov.tn/index.php/fr/
  - National Environmental Protection Agency ANPE http://www.anpe.nat.tn/Fr/
  - Tunis International Centre for Environmental Technologies CITET http://citet.nat.tn/
  - Coastal Protection and Planning Agency APAL http://www.apal.nat.tn/site_web/index.html
- **Official websites**
  - Tunisian Government Portal http://www.pm.gov.tn/pm/content/?lang=en
  - National Portal of Legal Information http://www.legislation.tn/en
  - Tunisian Industry Portal http://www.tunisieindustrie.nat.tn/fr/home.asp
  - National Institute of Statistics http://www.ins.tn/en/statistics-tunisia-national-institute-statistics
  - National Agency for Energy Management ANME http://www.anme.tn/

3.9.3.1. The Semi-Quantitative Component of Data Collection to Estimate Waste Tyre Inventory that Entered the Waste Stream

Quantitative methods are characterized by measurable data, which can be expressed in numbers or other quantities (e.g. in this study stocks of ELTs arising). To quantify the number of waste tyres generated in the country, the researcher used two methods to estimate the number of waste tyres produced in the Tunisia context. The method was based on statistical data obtained from secondary sources about the number of cars registered on the road. The secondary data were obtained from the national government (i.e. the Technical Agency of Terrestrial Transport [ATTT] affiliated to the Ministry of Transportation, National Institute of Statistics [NIS] and other official documents). Owing to the lack of statistical data about the number of waste tyres generated in Tunisia, the researcher used two different methods to estimate waste tyres numbers. The study at this stage focused only on passenger cars (private cars). Passenger cars tyres seem to enter the waste stream faster compared to heavy vehicles, such as truck tyres, buses, heavy commercial vehicles, prime movers, trailers and semi-trailers, fire fighting vehicles and equipment used in areas such as agricultural, mining and construction and demolition. This is because the heavy motor vehicles' tyres are designed with sufficient tread thickness and thus, can be retreaded three to four times before being finally discarded (Van Beukering and Janssen, 2001; Nkosi et al., 2013). For this reason, the light motor vehicles tyre management and disposal needed immediate attention.

Using secondary statistical data allows this research to provide a response to one of the objectives that it seeks to address: namely, comprehension of the number of waste tyres that the country has to dispose of annually. Moreover, quantification data is critical in knowing the tyre data and trends, and selecting the best methods of handling and utilization of waste tyres. It will assist in development of a consistent approach to tyre regulation, reforming policies and implementing new approaches to recovery and recycling technologies to process waste tyres, and ensuring that available recycling options are taken up, where available and viable.

The estimation methodology is divided into two parts and is based on assumptions and estimations to quantity inventories of waste tyres generated in the Tunisian context over a five year period (2008-2012), according to data on the number of registered passenger cars on the road.

Method I: This method is based on the premise of the estimation of cars tyre generation by using the number of cars registered on the road, distance travelled and estimates of average tyre life. This method was calculated in accordance with the use of car tyres for a period of five years (2008-2012).

Method II: This method was based on the premise of the replacement factor (multiplier) of car tyres annually in the country. This replacement factor is used by the tyre industry to determine the number of car tyres replaced yearly. The numbers calculated in the present research from methods I and II are rough estimates and should be considered as such.

3.9.3.2. Systematic Review (SR) to Assess the Life Cycle of Waste Tyres

The purpose of the systematic review of LCA studies in order to synthesise the best available evidence on the sustainable management options for final destination for end-of-life tyres from a LCA perspective that may be viable over the long-term for Tunisia. Using this method of systematic review enables the researcher to learn from other studies before deciding whether a new LCA is required.

The researcher conducted a systematic review of LCA of end-of-life tyre disposal by following a guide proposed by Boland et al. (Eds., 2013) and Zumsteg et al. (2012) as follows:

Step 1. The question formulation should be clear to establish the focus of the study and to frame the inclusion criteria.

Step 2. Locating studies: where the researcher should locate, select and evaluate the most relevant studies. This goal is achieved through research into the literature by scientific search engines using keywords and abbreviations.

Step 3. To select the relevant studies and evaluate them: in this step requires defining a number of inclusion and exclusion criteria in order to focus and extract important and relevant research papers.

Step 4. A process of analysis and synthesis, to extract unified information from the relevant papers in accordance with the questions that have been designed to describe work.

Step 5. To prepare a report and use the results, as the systematic review results are reported as an empirical report, which includes the introduction, methodology, findings and results, and conclusion.

3.9.3.3.1. The Methodology Steps to Extract Data

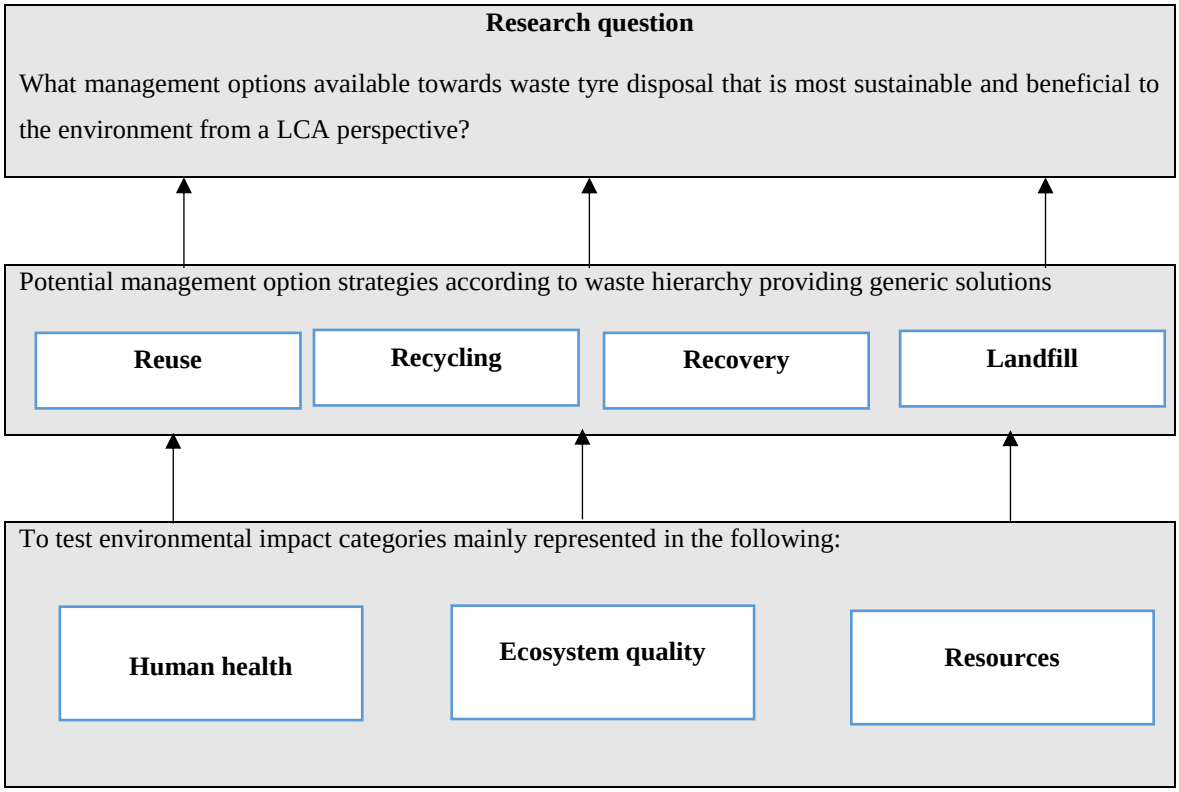
3.9.3.3.1.1. Research Design

The study has adopted a systematic review approach to the research. The systematic review is guided by the publication *Doing Systematic Reviews: A Student's Guide* (Boland et al. [Eds.], 2013).

3.9.3.3.1.2. Research Question

The research question was designed according to the technique of systematic mapping to address an open-framed question, as described in Figure 3.2.

Figure 3.2 Designing the Open-Framed Question



Source: The author

The purpose of this research question was to explore methods that can be used to dispose of used tyres, in order to determine if waste reduction, recycling, resource recovery or disposal is the best practicable environmental option from an LCA perspective. This process envisaged that the information obtained from the study would assist Tunisian waste management institutions and tyre importers or tyre manufacturing industry in making decisions regarding used tyre disposal options.

3.9.3.3.1.3. Research Strategy and History

As referred to previously, this study is based on a scientific literature review. To identify relevant literature for review and analysis in this study, four electronic databases were used to search for literature with keywords such as "life cycle assessment/evaluation/analysis", "LCA", "Waste tyre/tire, scrap tyre/tire, rubber tyre/tire", "end of life tyre/tire" and so on. The search was constrained by the use of “was only used with the term” “Life Cycle". The databases and the dates of the searches are summarised in Table 3.4.

The researcher chose to use the four electronic databases as shown in table 3.4 for several reasons, as follow:

- Web of Science covers all areas of science and therefore spans the literature from ecology to plant science, from genetics to biochemistry to chemistry to medicine, including the "best" journals of each subject area. In addition, Web of Science can track citations;
- Scopus is similar to Web of Science. Scopus is more comprehensive and is the largest database, including journals, and some conference proceedings. However, Web of Science is considered as more selective in choosing the best journals;
- Science Direct, which provides access to a large database of scientific and medical research, with coverage of both books and journals. The journals in Science Direct are grouped into four main sections: Physical Sciences and Engineering, Life Sciences, Health Sciences, and Social Sciences and Humanities. In addition, one of its advantages is that it has a check box that limits searches to peer-reviewed sources;
- Google Scholar contains a variety of disciplines and sources such as articles, theses, books, abstracts, from academic publishers, professional societies, online repositories, and universities, as well containing "grey literature". However, while Google Scholar is easy to use from one place, it has disadvantages in terms of sometimes missing important articles.

Table 3.4 Database Search Engines

No.	**Database Engine Name**	**Date Searched**
1	Web of Science	25 April 2017 - 20 May 2017
2	Science Direct	05 May 2017 - 21 May 2017
3	Google Scholar	11 Nov 2017 - 31 Dec 2017
4	Scopus	25 May 2017 - 20 June 2017

Developing comprehensive search objectives is one of the characteristics of a systematic review (Hunt, 2018). Hence, the search literature adopted by the study aimed to identify all relevant studies that met the inclusion criteria. The search terms were customised for each database that holds the same terms and phrases, using variations in the characteristics of the database language such as field tags. The search strategy thus combined two sets of keywords using "OR" and "AND" strategy.

The general search terms for scoping and evaluation were tried from different search histories in the systematic review, as illustrated in Appendix 3.6. The approved keywords selected for this study focused on the terms "LCA" OR "environment* impact" OR “treat* impact” AND "waste tyre" OR "waste tire" OR "scrap tyre" OR "scrap tire" OR "rubber tyre" OR "rubber tire" OR "end-of-life tyre" OR "end-of-life tire".

3.9.3.3.1.3.1. Types of Outcomes

The studies considered for review were expected to yield the following: evidence of implementation of the life cycle assessment/ evaluation/ analysis/ for waste , scrap, used or end of life tyre management to assess environmental impacts from the international literature or any other relevant LCA and scrap tyre and/ or treatment option or management option; rubber tyre management falls under the category of reuse, recycling, recovery and or landfill to evaluate environmental impact categories such as damage to human health, climate change, ecosystem quality or resources, according to ISO (2006).

3.9.3.3.1.3.2. The Inclusion Criteria of the Review

Criteria should be defined for the selection of LCA for waste tyre studies. In this study, the selection required the specification of a set of criteria to define the homogeneity of the material reviewed. In this regard, the criteria used in the present review are:

1. Studies of Life Cycle Assessment for waste tyres examining the reuse, recycling, recovery and landfill scenarios which focus on the ELT products were included.

2. Studies included should follow ISO standards (ISO 14040:2006 and ISO 14044:2006) LCA standards.

3. The study must have been published between 2006 to 2017 and published in the international literature.

4. Studies written and published in English were considered and those in other languages were excluded.

5. Studies of LCA were included that at least covered applications of ELTs treatments, otherwise they were excluded.

The search was restricted to the period between the years 2006 - 2017. The year 2006 was taken as the base year for the search of literature because of the landfill ban on tyre waste within some states of the USA and within the EU starting from 2003 - 2006, and where the EU has since that period witnessed development of tyre waste treatment (European Directive 1999/31, Landfill Directive; Rubber Manufacturers Association, 2004). In addition to that, in the year 2006 the new international standards for LCA (ISO 14040-14044, 2006) were published, specifying the requirements and providing guidelines for LCA including: definition of the goal and scope of the LCA, the LCI analysis phase, the LCIA phase, and the life cycle interpretation phase (Finkbeiner et al., 2006).

3.9.3.3.1.4. Methods of Processing Retrieved Citations

Once the titles and abstracts of different studies identified were examined for relevance, the selected studies to be retrieved were subjected to an initial study using an eligibility form (see Appendix 3.7). Studies whose titles and abstracts were irrelevant to life cycle assessment/ evaluation/analysis of waste tyre or environmental impact of end-of-life tyres were excluded at this stage. While those that referred to or were quite explicitly regarding life cycle assessment/ evaluation/analysis of waste tyres or the environmental impact of waste tyres were subjected to assessment for relevance. All selected studies were downloaded from the electronic database and exported to EndNote (a commercial reference management software package, used to import and manage bibliographies and references or citations when writing essays and articles); at this stage, duplicates were detected and eliminated. However, studies that lacked either detailed abstracts and /or titles for decision-making or those that had an abstract and titles which were not detailed enough for decision-making, could not be excluded at this stage. In this regard, the text of such studies was, therefore, read thoroughly to determine the possibility of their inclusion.

3.9.3.3.1.5. Data Extraction Methods

The data was extracted using a standard data extraction form, focusing on elements such as: general characteristics in terms of metadata of the studies; standard compliance in terms of characterisation of how ISO standard was handled; goals and scope of the study is clearly defined in terms of objectives; functional unit and system boundaries; geographical scope, etc. (See appendix 3.8), which helped the process to pick up relevant information from the

studies included. The purpose of using the standard data extraction form was to ensure that the extracted data was formal and systematic, as well as enhancing consistency and objectivity. Moreover, a data extraction form helped to find the gap in terms of what was reported by the authors. The data extraction form played an important role in the systematic review. Firstly, a data extraction form is connected directly with the review question. Secondly, the data extraction form gives an accurate summary of what should characterise the defined studies. Thirdly, it acts as a historical record of any decision (and changes thereto) that characterise the whole review process. Finally, it works as a resource of data for inclusion in the analysis.

Given the significance of a data extraction form in a systematic review process, adequate time was set aside for the development of the standard data extraction form used in the current study. This was deemed necessary for the purposes of ensuring a reasonable balance between collecting too much and too little information, and avoiding the omission of certain crucial data. The following descriptive data were extracted: (i) study location; (ii) type of technology treatment; (iii) impact categories in study; (iv) methodology used to examine environmental impact; (v) type of data and sources used (primary and secondary data) (vi) outcomes of Life Cycle interpretation; (vii); any other information relevant to the review.

3.10. Thematic Analysis

The analysis of the data gathered during the research involves summarising the mass of data and then presenting the outcome in a way that communicates the most significant finding or features. Because the nature of the research produced mostly qualitative data, these were analysed thematically. Meanwhile, another part of this research produced quantitative data that were collected from secondary sources and analysed statistically to estimate the volume of waste tyres in the country, using an equation based on the cars registered on the road.

Guest & Namey (2012) emphasise that thematic analysis is considered the most popular form of analysis in qualitative research. Thematic analysis is an analytical method for identifying and analysing patterns or themes that recur and emerge from the qualitative data (Clarke & Braun, 2013). Thematic analysis is a helpful approach used as a tactic for reducing and managing a large volume of data without losing its context; for getting close to the data; for organising and summarizing data; and for focusing the interpretation (Boyatzis, 1998). In addition, it allows for a detailed and complex description of data (Javadi & Zarea, 2016). Thematic analysis is suited and can be used to analyse different types of data such as transcripts, field notes, supporting documents (such as journals), information written by

participants (diaries), pictures, drawings, maps, digital audio files and video files (Guest & Namey, 2012; Joffe, 2012). The technique used for interpretation was an adapted manual analysis of the results. The manual method was adopted as opposed to using computer software that allows for more interaction, to better understand the data context (Robinson, 1998; Flowerdew and Martin, 2005). In this research study, the researcher used thematic analysis to analyse results from interview and observations in order to describe waste tyre practices in the Tunisian context and to identify repeated patterns and meaning of themes. Interviews were transcribed literally and compared with field observations that were noted in the field for a cross-check. The transcripts were coded thematically in order to disclose pertinent and developing themes. The transcripts were further organised and analysed in order to determine the main feature of themes, concepts and relationships within the data as well as between the data and literature. In consideration of ethical guidelines related to the privacy of participants, codes were given to all participants interviewed as a replacement for their real names.

3.11. Ethical Issues

The researcher understood the main ethical issues in the research, which enabled the design and execution of an ethically acceptable study. The researcher obtained ethical approval from the University of Salford (Ethical Approval Panel) in order to conduct the interviews (see Appendix 3.9). In this research, which involved human participants, it was important to observe all ethical guidelines. Gilbert (2008) observes that the ethical guidelines for research concerning human subjects, in order to protect the rights of others, require that anonymity or confidentiality is guaranteed, consent is informed, dignity is maintained, and on balance, the individual and society receive more benefit than harm. In addition, Robson (1993) advises that the researcher should inform all participants of the objectives of the research and explain all of its aspects, including any intervention that might reasonably be expected to influence willingness to participate.

During the fieldwork, the researcher obtained approval and consent from all participant stakeholders before collecting any primary data. Participants were informed about the nature, duration, methods, and purpose of the research before they decided to participate. Participants were they given the right to decide freely whether to participate in the research, and also had a right to withdraw from the research at any time they felt they could not continue, without giving reasons. Participants were asked to fill and sign the consent forms to show their acceptance to take part in the research. The researcher was responsible for

ensuring anonymity and confidentiality of the participants throughout the research process. At the end of fieldwork, all data collected by the researcher were stored and used in a manner that ensured no one but the researcher knew the details and sources of the data, thereby guaranteeing confidentiality and anonymity.

3.12. Methodological limitations

One limitation inherent in this study was the change of direction in the context of the country of study. It must be noted that this study originally focussed on the Libyan context, but due to the deteriorating political situation and potential danger (reference using foreign travel advice, Libya https://www.gov.uk/foreign-travel-advice/libya), the focus had to be shifted to Tunisia in order to safely access key organisations. The University's health and safety officer raised the issue due to the 'extreme' rating for Libya on the Government's travel website, preventing any form of research engagement within that context. An alternative location was chosen, which was Tunisia, due to its cultural similarities to Libya. However, there were still issues surrounding access and gatekeepers needed to make connections in this alternative context; results could then be compared with the original Libyan context, enabling lessons to be learned. In Tunisia, the researcher presented himself as a Ph.D. student to several gatekeepers; this process was somewhat difficult due to the lack of prior connections. Nevertheless, the researcher cooperated with an NGO for help and cooperation for the purpose of communication and arrangement with the state institutions and other parties, employing the Arabic language when people were non-English speakers.

Therefore, the collection of data for the research was affected by the most important factor, which limited the amount and quality of information gathered for this investigation. The greatest challenge faced by the researcher was the limited sample size, and language communication. The sample size that was targeted, representing the key stakeholders, was limited due to the inability of the NGO to access appointments and interviews with some of required parties (some of the importers of brand name tyres, recycler companies and other targeted municipalities at other governorates) due to the limited available timeframe and limited budget. Within this limited budget and time, the research could therefore not achieve its target with regard to the coverage of all parties and the amount of data to collect. In terms of language, the majority of Tunisians speak Arabic and use up to 60% French vocabulary in their daily life, as well as in government departments. In addition to this, most of the research and studies were written in French, which increased the burden on the researcher in the translation process for secondary sources. During the interviews, an interpreter from the

NGO helped the researcher to translate French to Arabic, which helped to further clarify the concept for easy understanding by the researcher. These obstacles led to the study being conducted in a tight timeframe and limited budget.

CHAPTER FOUR: RESEARCH RESULTS - TYRE WASTE MANAGEMENT IN TUNISIA

4.0. Results

This chapter of the research results has divided into two sections:

The research results for section one, to fulfil the first three objectives, related to data gathered from the interviews and fieldwork observations conducted in Tunisia using qualitative methods to fulfil research objectives regarding current practices of waste tyres management system in Tunisia. This data collection encompassed waste tyre behaviour and its effects on the environment, and also status and effectiveness policies and regulations that were currently in place to manage such waste. A semi-quantitative method was utilized to gather statistical data on the number of vehicles on the road in order to fulfil the research objective related to quantifying waste tyres accumulated during a period of time in Tunisia.

The research results for section two to fulfil the fourth objective, related to the most sustainable final destination for end-of-life tyres based on the LCA studies gathered by using systematic review guidance proposed by Boland et al. (Eds., 2013) and Zumsteg et al. (2012).

4.1. Results of Section One:

4.1.1. Introduction

This chapter presents the results of an investigation concerning how tyre waste is managed in the study area by using a qualitative methods approach through interviews and field observations. The study was conducted in order to understand the current waste tyre management practice using field observations at workplaces and in the area surrounding or nearby the business activities, to gain an understanding of the real situation on the ground. Additionally, information was collected from interviews with stakeholders. Table 4.1 provides a summary of the methods adopted for data collection – these are coded and referred to throughout the chapter. With regards to the waste tyre arising in Tunisia for a certain period of time, the researcher used a quantitative method approach in order to estimate the waste tyre quantities disposed of for this period.

Table 4.1 Method Used for Data Collection

Method code	Summary	Number of participants
OBS	Observations by the researcher in the study areas	6
MESD	Interview with the representative of Ministry of Environment and Sustainable Development	1
ANPE	Interview with the representative of National Environment Protection Agency	1
CITET	Interview with the representative of Tunis International Centre for Environmental Technologies	1
ANGED	Interview with the representative of National Agency for Waste Management	3
WTRC	Interview with the representative of the Water Technologies Research Centre	1
FMACM	Interview with the Former Member of Al Zahra Council Municipal	1
TOCI	Interview with the representative of Tunisian Organisation for the Consumer Information (NGO)	2
EHS	Interview with the representative of the Environment and Heritage Society (NGO)	2
Dealer	Interview with the waste generator (Dealer, garages and shops for sale and repair/ replacement of tyres) and informal waste collectors	13
SL	Interview with the representative of Scrap yard and landfill.	3

In respect to interviews, where information or a quote is attributed to a particular participant this is denoted by an abbreviation code plus number in case of more than a participant from the same institution. For instance, in cases where more than one person per category/organisation/ institution was interviewed, participants are given the same abbreviation code plus a number e.g. (ANGED-1), (ANGED-2), (ANGED-3) and so on. Where applicable, this information has also been supplemented by secondary information that was recommended by those interviewed or subsequently found by the researcher.

Due to a mixed methodology being adopted there is a crossover and exchange on the data to tackle waste tyre management issues in terms of the tyre flow and generation of waste tyres in Tunisia in order to fulfil the research objectives 1, 2 and 3. In addition, to reduce repetition between data obtained from a different group of interviewee and field observations, the results have been synthesized under themes and information presented throughout the chapter. This section explains the nature and characteristics of the study area. It is followed

by the SWM structure in Tunis, including the roles and responsibilities of key stakeholders. This is followed by waste tyre management practices in Tunisia.

4.1.2. Waste Tyre Management in Tunisia

This section covers waste tyre practices in the Great Tunis area. The results are synthesized from the mixed methods applied. The section covers data about the sources of waste tyre generation, levels of waste tyres arising, funding of services, and the collection and disposal system. The challenges that impact the delivery of an effective waste tyre management system have also been highlighted.

4.1.2.1. Sources of Tyre Waste Generators

Keeping tyres in good condition is crucial to driving safety because tyres provide the only contact point between the car and the road. Therefore, it makes good sense to pay attention to tyres in terms of their condition as much as using the car, by checking the tyre tread. Tread depth is extremely important; thus, when it reaches the legal level it becomes worn out. Tonnes of worn waste tyres are discarded across the country every year. Disposal of waste tyres is a challenging task because tyres have a long life and are non-biodegradable. The tyres become waste when they have worn out and are no longer suitable to use (Nkosi et al., 2013). The main generator of the waste tyre in the country context are dealers[3] (importer, garages, car care shops and vehicle scrapyard) as shown in figure 4.1 (A & B).

[3] Tyre Dealers (Workshops) Tyre dealers refer to the tyre importer and workshops where consumers repair/change and discard their tyre in the shop. Therefore, these business premises are waste tyre generating sites. Tyre dealers usually store scrap tyres inside and outside of their shops in order for the collectors to cart the scrap tyres away from their business premises and send them to recycling facilities or they are disposed of in landfills.

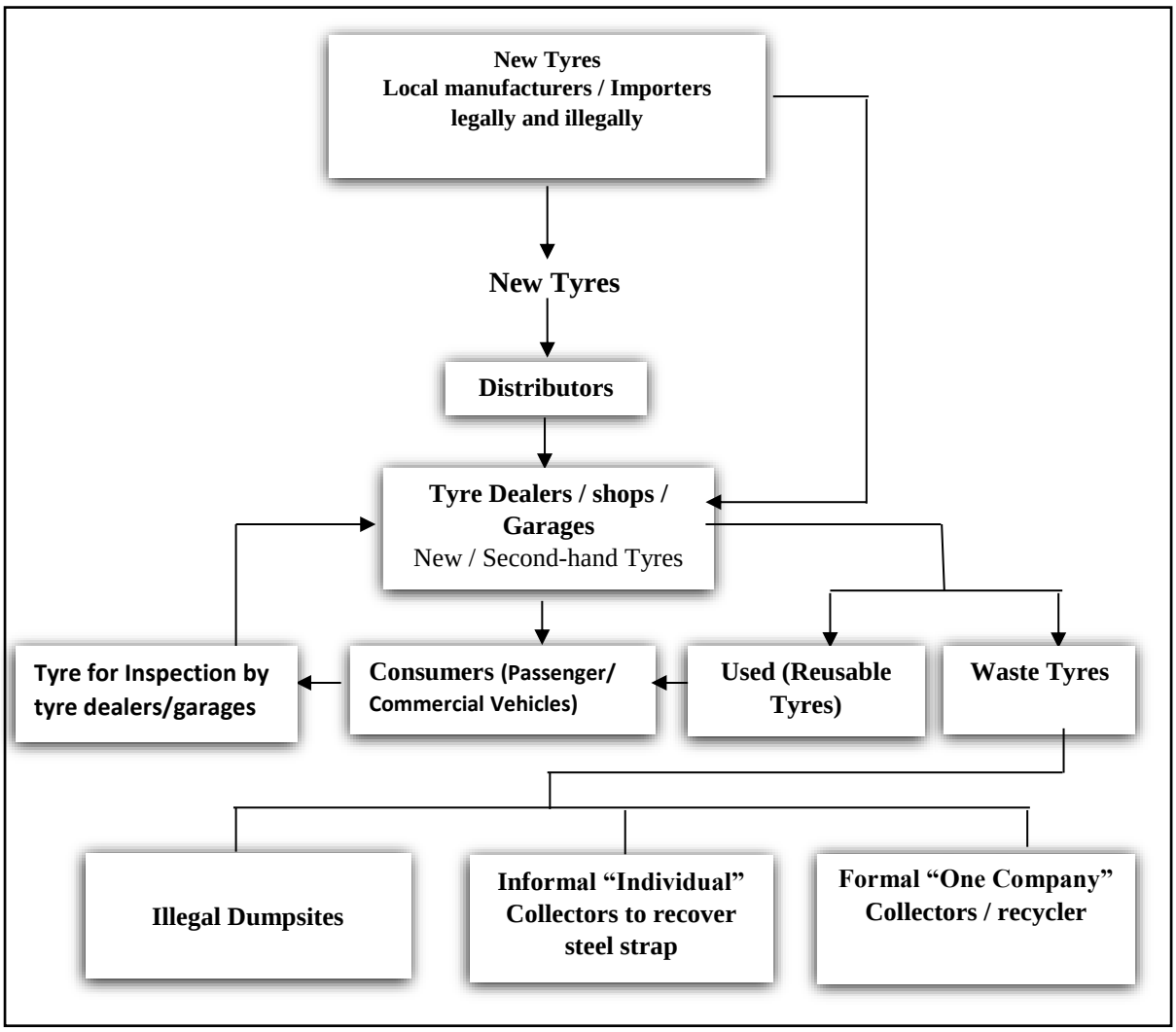
Figure 4.1 (A & B) Shows the dealers or tyre care shops as one of the main generators of waste tyres

Source: The Author

In this regard, one of the interviewees (Dealer-3) was a tyre dealer the researcher met to describe the process of how they are dealing with tyres when they become unusable. He stated, *''usually the customers leave their used tyres at garages or shops after replacing with a new one. Although there is no legal obligation to accept end life of tyres, it is customary in Tunisia that the services we provide customers include accepting to keep waste tyres in our premises".* On the other hand, the participants (Dealer-1, 6, 7, 9 and10) admitted that the undamaged replaced tyres that they accepted from customers that had a good body with enough tread depth were sorted to resell them as second-hand tyres. One participant (Dealer-3) explained that there were three different categories of tyres to sell it to customers (new

tyres, second-hand tyres, and retreated tyres). The interviewee (Dealer-6) stated that the new tyres which flow into Tunisia come from two sources: "*one source is locally manufactured and the other it's imported from abroad*". He continued to say that *''Imported tyres are either by legal channels or illegally by smugglers; this latter is illegally sold in the shops or garage, and sources of smuggled tyres come from the Tunisian border, either Algeria or Libya"*; these are the so-called informal activities (covered in section 4.1.2.2.1.). There are close links between informal economy activities and smuggling of goods, including tyres, at the Tunisia border (Trabelsi, 2014). Figure 4.2 offers a flowchart that describes the steps of tyre flow in Tunisia.

Figure 4.2 The Steps Tyres Follow in Tunisia



Source: The author

Concerning the formal trade as a source of tyres that flow into Tunisia, one participant (Dealer-13) described that the national manufacturer in Tunisia, known as the Society of

Pneumatic Industries (STIP) was responsible for rubber tyre production and distribution. This company was founded in 1980 in the framework of an international-Tunisian partnership and it produces tyres for passenger cars and small trucks, and heavy-duty trucks and buses. The company owns two production units, one located in Masakin and the other located in Manzil Bourguiba. As reported by the interviewee (Dealer-10), the company is manufacturing certain types of tyres, *"these types of tyres are not allowed to be imported from abroad by importers, where it is limited to be manufacturing locally only as a quota to encourage local manufacturers"*.

However, other interviewees (Dealer- 9) and (TOCI-2) stated clearly that the company was in a financial crisis due to many reasons; one of those reasons was that the market was flooded by smuggled tyres from beyond the border, which affects formal tyre importers and local tyre manufacturers. Although, the interviewee (Dealer-10) emphasised that the company *"imposed quotas on the tyre dealers who wish to import tyres from abroad in exchange for the obligation to buy the number of tyres from Tunisian tyre manufacturers under the interest of promoting the national product"*. While the other source of tyre flows to Tunisia was through tyre importation ("traders"), who were the formal importers of tyres from abroad; they were subject to a series of measures to get a permit for the importation of these tyres. In relation to this, the interviewee (ANGED-1) described, *"The importation of tyres from abroad is subjected to taxation with the requirement to obtain a permit or authorisation for each customs clearance process"*.

4.1.2.2. The Informal Sector

The results in this section shed light on the informal sector in terms of informal tyre trading and informal recycling. The informal sector is also known as the "grey economy" or informal economy (Akintimehin et al., 2019), i.e. that part of the urban labour force that operates outside the formal labour market (Hart, 1973). The informal sector is on the increase in Global South countries, including Tunisia, and provides employment and income. The informal sector includes many workers who are self-employed are earning a living through self-employment without being subject to payrolls, thus are not taxed. Many informal sector activities within the grey economy are unrecorded, unrecognised, unprotected, unregulated and are in unsecured places that may face high levels of risk (Scheinberg & Savain, 2015). Examples of the informal sector include minor traders, small-scale producers, and a variety of casual jobs. In Tunisia, the informal economy represented 30 per cent of Tunisian GDP in 2010, which then increased to 38 per cent in 2013 (Trabelsi, 2014). In the context this

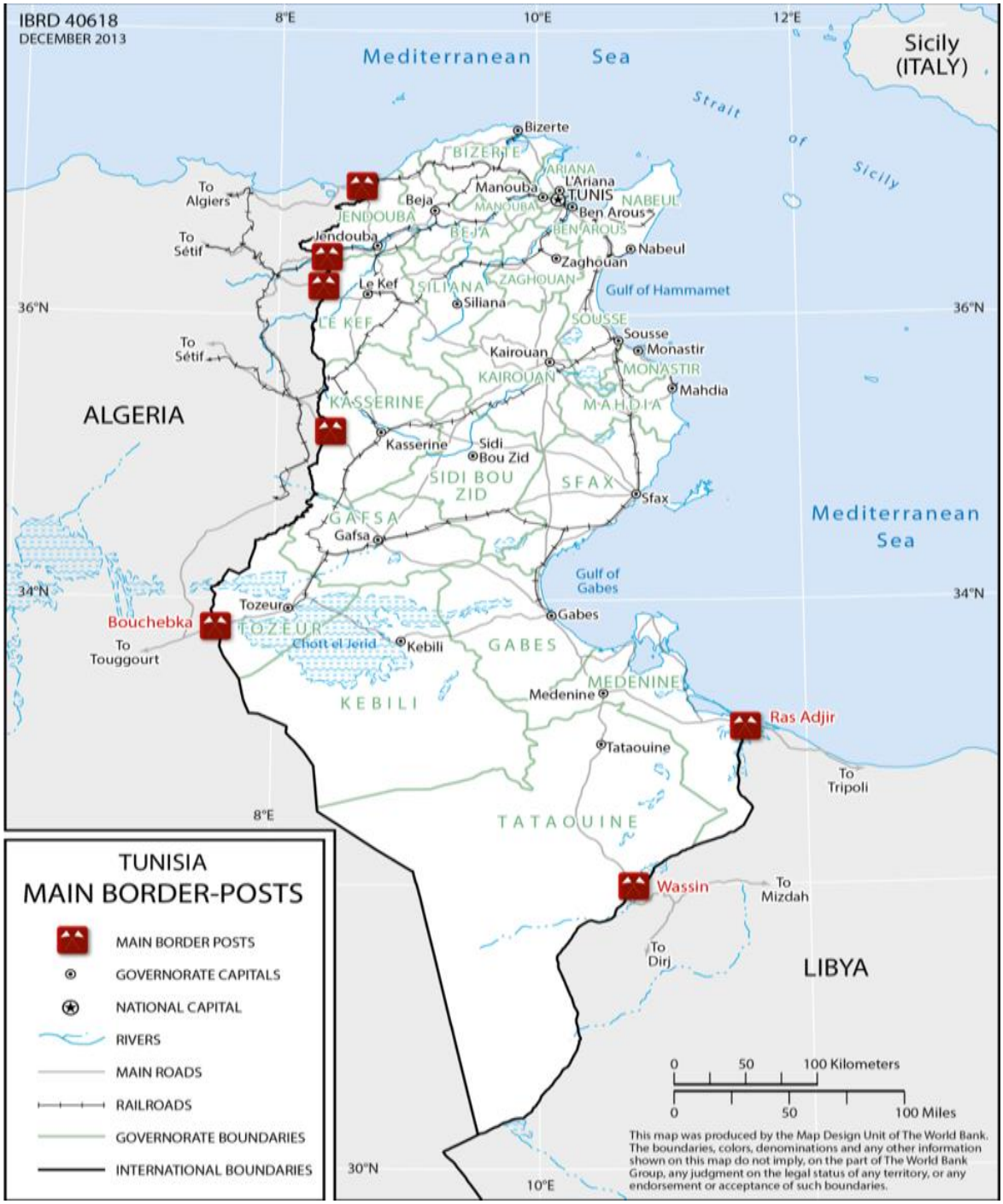
section addresses, informal sector activities encompass tyre smugglers, while the waste tyre pickers or scavengers and informal waste tyre collection and recycling are presented in section 4.1.2.3.2. There are close links between informal economy activities and goods smuggling, including tyres smuggled in between the Tunisian border (Trabelsi, 2014).

4.1.2.2.1. Informal Tyre Trading in Tunisia

Informal importation of tyres without quality check-controls may also encourage the dumping of poor-quality products in this country. Poor quality tyres have a short life span and therefore exacerbate the problem of waste tyre generation and accumulation. Such poor-quality tyres find their way onto the market at numerous poorly manned custom points in Tunisia.

Informal tyres imported by smugglers are offered at low prices, which is often because they were not manufactured for the local climatic conditions, they wear or are damaged far too quickly and increase the rate at which waste tyres are generated. The informal discussions with (EHS) and (ANGED-3) revealed that the phenomenon of smuggled tyres within the grey economic mostly resulted from the difference in price between Tunisia and bordering countries (Algeria and Libya). Tunisia has two land border countries. Tunisia's western border with Algeria has a border length of approximately 965 km. Whilst, the south-eastern border with Libya is 459 km long, as shown in figure 4.3. Meddeb (2012) confirmed that the phenomenon of informal trade between borders is relatively old, and grew up in the era of the former regime in the 1990s, but after the revolution on 17 December 2010, this phenomenon grew exponentially. In this context, Benjamin et al. (2014) state that informal trade is common in the Maghreb countries. While trade policies in the region are similar to some extent between the Maghreb countries, domestic support policies vary greatly between countries, especially between the oil-exporting countries and importers, leading to strong price differences across borders.

Figure 4.3 Tunisia Map with Main Border Posts



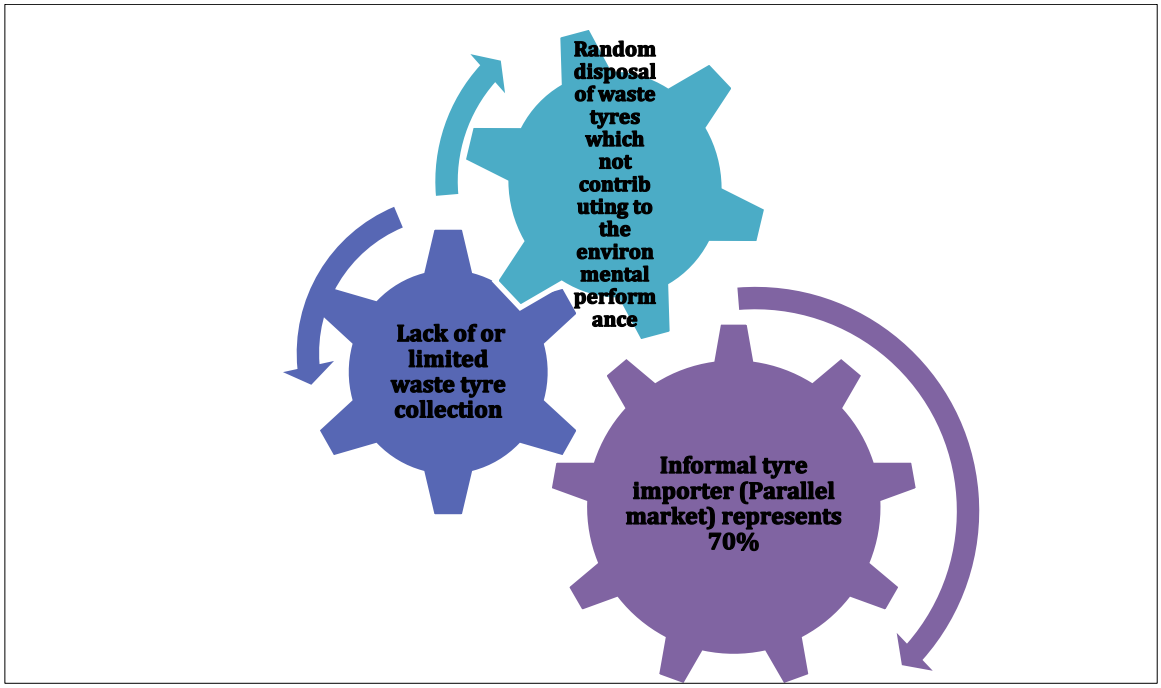
Source: Ayadi et al. (2013, p. 6)

It is argued that Tunisian authorities 'turn a blind eye' to the smuggling of goods between the border areas with Libya and Algeria (France Channel 24, 2015); hundreds of types of goods such as fuel, electronics, foodstuff, cigarettes, tyres etc., are smuggled from Libya to Tunisia. The interviewee (TOCI) said honestly, *"The most important smuggling market in Tunisia is located on the Tunisia border and is called Market Libya in Ben Guerdane"*. In

this market, you will find all kinds of goods, and at very attractive prices, and there are other areas in Tunisia living on smuggling, which animates its economy. Besides this, another interviewee (ANGED-1) pointed out that the causes of the smuggling activity on these border areas were *"the result of high tariffs and excise duty and other taxes on goods and complex procedural restrictions, forcing people to resort to smuggling operations when they find a big price difference with neighbouring countries"*. Meanwhile the participant (TOCI-1) stated that the Tunisian state is the number one sponsor for this type of economy, first through its failed economic policies for development, which have created significant gaps between the different classes and rendered some of them economically moribund, and secondly, through the pervasion of corruption inside its administrative and regulatory bodies and its security forces, and thirdly, through its ineffective and unjust tax policies.

According to the interviewees (EHS-1) and (ANGED-12) the parallel market (informal) for imported tyres had become a monopoly for more than 70 per cent of the total local needs of this product. Moreover, the interviewee (ANGED-1) stated that the desire of people to buy a tyre from the parallel market is *"the result of a lack of awareness of the extent of seriousness on the one hand, and to the lower prices that entice the buyer on the other hand"*. In addition, they pointed out, *"The difference in price between the high-quality tyres and tyres that are sold on the grey market does not exceed 5 per cent"*. In addition, the participant (TOCI-2) cited that all of these factors supported the parallel market significantly and at the same time *" increase the size of the accidents as a result of poor quality of tyres that spread in Tunisia, thereby [causing] increases in the generation of waste tyres in larger amounts than expected"*. As Cowley et al. (2006) underlined, many people are killed in vehicular crashes, as is well known, but it is less well known that a substantial number of crashes are caused by improper vehicle maintenance and defective tyres. This confirms that the informal trade of poor quality tyres may potentially have led to deaths in Tunisia context. In fact, source reduction does not mean that waste tyre will not be generated. It only means that the waste tyre generation will be reduced. Correct tyre utilization in vehicles, which includes fitting suitable types of tyres, maintaining tyre pressure as well as an aligning and rotating of tyre regularly, are essential measures that not only increase the lifetime of tyres but also improve the safety of tyre utilization on vehicles. The following figure 4.4 summarizes the uncontrolled and random distribution of new "smuggled" rubber tyres that threatens the local resource (formal importer) and the safety of citizens, and increases waste tyre numbers.

Figure 4.4 Summarise the System of Informal Tyre Imports



Source: The author

Consumer awareness is necessary to build appropriate attitudes towards tyre utilization. This, jointly with effective policing of rules and legislation governing tyre tread depth, will contribute to the minimisation of the generation of non-retreadable used tyres that should be disposed of as waste.

In this context, (ANPE) indicated that *"it is necessary to tackle the tyre smuggling problem that produces poor quality tyres and that is contributing to exacerbate waste tyre generation and their accumulation in the country"*. There are many studies that have dealt with the phenomenon of goods smuggling between borders in the countries of the Maghreb, including Tunisia. One of the studies was by the World Bank, it dealt with tyre smuggling issues.

4.1.2.3. Storage, Collection and Recycling of Waste Tyre

4.1.2.3.1. Waste Tyre Storage

The researcher observed that most dealers, garages and shops for selling and replacing tyres in Great Tunis do not have appropriate storage for a waste tyres to prevent fire hazards and excessive stockpiling. Usually, rubber tyres are not easily ignitable; however, when alight, they are extremely difficult to extinguish. When tyres burn, the high energy release rate results in a very hot fire and a considerable volume of smoke being generated, both of which

present a serious hazard to the community, environment and firefighters. The physical properties of rubber tyres create difficulties in extinguishing burning tyres. The shape of tyres and the tyre stacking arrangement results in many three-dimensional pockets, which are difficult to access or penetrate with extinguishing mediums. The researcher observed all the tyre dealers he visited were storing waste tyres that were unfit for any use in a random way around their premises, as shown in figure 4.5 (OBS).

Figure 4.5 Example of How Garages and Shops Store Tyre Waste

Source: The author

The participant (Dealers-5) expressed that *"those tyres which are returned by customers i.e. not anymore usable after being checked by a technician, are stored on the roofs of shops or garages, or in the front or rear courtyards in order to get rid of them later,'* as shown in Figure 4.6.

Due to the hazardous nature of rubber tyre storage, the relevant planning authority should strictly require from any facility related to tyre dealing to be subject to 'Fire Safety' in terms of identifying maximum stack sizes and minimum distances, to assist fire services to contain and extinguish tyre fires (EHS-1&2).

Figure 4.6 Example of How Garages and Shops Store Used Tyres on their Roof

Source: The author

4.1.2.3.2. Waste Tyre Collection and Recycling

There was no obvious sign of waste tyre collection and recycling seen at the Tunisia level during observations and this was confirmed during interviews with the stakeholders. As highlighted in the interviews below, it appears there have been attempts to engage some companies in the recycling, but without any success.

The collection of waste tyres from generators such as garages, shops and dealers should be made only by organisations that are registered as waste carriers. All participants (Dealers) emphasised there was no registered organisation to carry out any part of the operation in terms of collection, transportation and recycling in a regular formal way. They further noted that there was no waste tyre collection undertaken from tyre generators in order to take the waste tyres to designated collection points. The participant (MESD) stated clearly, *"The National Agency for Waste Management (ANGED) is responsible to undertake waste collection and disposal, where this function is conducted by private companies on behalf of ANGED that grants them a licence for collection and recycling of waste tyre"*. The interviewees (Dealers-1, 7, 8, 10 and 13), (TOCI-2) and (EHS-1) described that waste tyres were collected informally, on one hand by individuals to recover steel straps by burning tyres in order to sell to metal dealers and industrial manufacturers. On the other hand, they also reported collection of waste tyres by informal collectors for the benefit to a private company called Ecobeno, for tyre recycling. In this regards, the research revealed there is no standard format for waste tyre collection, and no body that holds all the relevant information about

the parties who are producing, transporting and receiving tyre waste, such as amount, description, waste catalogue code, addresses, carriers number, and recipient's waste management licence number. The participants (Dealers 1 ,7,9 & 13) and the informal waste collectors emphasised during the interviews, that this information did not exist at all, or the relevant authority requested them to record or to keep such relevant documents in terms of the monthly number of waste tyre generated or stored or that which were disposed of. In turn, the representative of CITET stated *"Expressly the waste tyre generators are not obligated or subject to any responsibility of ensuring that the waste tyres are transferred to authorised persons, for example, registered waste carriers and/or licensed or exempt waste sites. Indeed, such a system, such as waste carriers or exempt sites for waste tyres, simply does not exist on the ground in Tunisia"*. Furthermore, the representative of the National Waste Management Agency (ANGED-1 & 3) expressed that the legal and regulatory framework for the ELT sector is insufficient and does not encourage investment in this area. In addition, he noted the lack of a well-organised institutional framework for the collection, transport and recovery of waste tyres, as well as problems related to the lack of financial support from the State.

The lack of a proper system of waste tyre management has allowed informal activities to flourish in Tunisia, such as the informal collection and recycling of tyre material. It is remarkable that the informal market for trading tyres is not only considered a source of business livelihood but also informal collection and recycling are considered a source of income to poor people. The interviewee (FMACN) stated, *''Waste [has] become a daily bread i.e. as a source of livelihood for waste pickers or scavengers or Albarbasha in Tunisia"*. "Albarbasha", as they call themselves in the Tunisian dialect, are people who search for valuable materials in the streets and in the random dumpsites in order to sell to recycling companies. The researcher observed one such Albarbasha on the street, who was picking plastic waste using his three-wheeled bike. As mentioned in the methodology, finding informal tyre waste collectors was very difficult, contrary to what I expected. Although the participant I found (a waste picker) was specialised in plastic waste collection, the interview was useful in gathering extensive information on this category of manpower regardless of the type of waste they are collected. In this regards, the participant (waste plastic picker) (Dealer-12) stated that "*as waste pickers we begin our work in the morning in the narrow alleys, roam the streets and in the landfill in search of valuable materials, which usually cannot be reached by municipalities or agents to clean*". He continued saying *"In reality, this job it's a risky operation, in which some have lost fingers or feet, others*

have been crushed by trucks as dumpsters are emptied. In spite of this work that we are facing in terms of daily catastrophes, in return, we get a few dinars at the end of the day, this just in order to feed our families". He continued, saying "*at present, we cannot directly access the collection points managed by ECOLEF as these are open only to holders of commercial licenses and have to be approved by ANGED. In consequence, the majority of us as 'Albarbasha' cannot benefit from the high prices guaranteed by ECOLEF and are therefore obliged to use intermediaries offering lower prices".*

The "Albarbasha" or "waste pickers" belong to the poor and marginalised classes in Tunisia, the core of their mission is to collect plastic bottles and bags and the remnants of aluminium cans, bottles, batteries, tyres and other materials that can be reused and recycled in order to get a few Tunisian Dinars' at the end of the day (EHS-2). The representative of (FMACM) explained, *"Personally, I am against this inhumane sector, and I don't think it is going to succeed. I guarantee that the Albarbashas do not wish to cooperate with any institution. They prefer to manage by themselves".* In fact, waste picking via Albarbasha is a source of livelihood for vulnerable groups. Albarbasha often comes from socially disadvantaged groups, i.e. those groups of people who are among the poorest and most vulnerable groups of society. This group often includes people who sometimes have more than one sick dependants, are raising children on their own, are women, are elderly living on very small pensions, or people with some kind of handicap or disease. This vulnerable group suffers both from being unrecognized by the government and from being denied access to basic social and health services, as well suffer from a lack of social integration (EHS-1).

Evidence demonstrates that the waste tyre sector faces several obstacles, mainly the lack of a collection, transport and recycling system. The collection and recycling of waste tyres are provided by the private sector. This study found that five private firms were granted permission and authorization by the Ministry of Environment to collect and recycle waste tyres, but only one of these five firms was still operating in the field of waste tyre recycling. The interviewee (CITET) stated that in fact *"most companies operating in this field closed their doors as a result of their bankruptcies in 2011, except one company called Ecobeno, although it continues to bear losses since its establishment in 2009, which has left it in a critical situation that may lead it to declare bankruptcy as happened to other units operating in this sector".* This company was dealing with informal waste collectors to ensure the collection of waste tyres according to the manufacturing capacity. In this regard, he

emphasised that the government should support and encourage recycler companies by implementing a sustainable system.

The representative of informal waste collectors (Dealer 13) expressed "*the supplying a waste tyre to Ecobeno recycling company depends on their demand, therefore, cannot be considered as a permanent job or a permanent source of income from them*". Due to the environmental importance of waste tyre recovery projects, it is facing many difficulties, mainly due to the lack of collection and recycling system in place to ensure sustainability. For instance, one of the other difficulties facing this sector was, *"that the imported rubber granules are not subject to any customs tariffs, but rather enjoy an exemption from value-added tax, while buying the same Tunisian product is subject to the payment of this tax"* (TOCI-1 & 2).

Data collection highlighted that the collection service of the waste tyre did not serve all waste generators by informal collectors in the context of Tunisia. The research revealed that the private recycling firm dealt with informal collectors according to the demand to collect and transport tyre waste to the company's premises for recycling. It was noted that this private recycling company was not capable of absorbing the entire tyre waste generated in-country, in order to recycle it. Although there were private firms that were mandated to manage waste tyre within the whole of Tunisia, observations indicated that their presence and service did not cover all the cities. In general, the research results revealed that the collection of waste tyres in Great Tunis was very poor, resulting in waste tyres being dumped in public spaces or in landfills mixed with other wastes. In this regards, GIZ and SWEEP-Net (2014) stated in this matter and the existence of an informal collection sector for waste tyres in Tunisia should encourage the government to put in place a transparent national strategy for the collection and recycling of this product.

4.1.2.4. Waste Tyre Disposal

Both representatives of the Ministry of Environment and Sustainable Development (MESD) and National Agency for Waste Management (ANGED-1) confirmed, "*There is no landfill designated for the disposal of a single material such as waste tyres as a temporary short-term solution in Tunisia*". The participant (EHS-1) stated clearly, *"Unfortunately, the decision-makers are not seeing this issue as a priority at the national and local level"*.

Moreover, the researcher's own observations and the interviewee (FMACM) confirmed, *"the waste tyres are disposed of mostly in an uncontrolled open dump or in the controlled landfills, whereas there are no restrictions on placing scrap tyres in controlled landfills"*.

He emphasised that many of these open dumps exist because of a lack of permanent disposal sites for this kind of waste. This was confirmed by dealers as they stated when they could not find a place on their premises to store emerging waste tyre (i.e. the storage become limited), they tended to get rid of this tyre waste in the nearest open dumpsite or controlled landfills. ANGED-3 stated that these open waste dumpsites were often located far away from human habitation because of the nuisances of smoke, bad odours, and vermin. However, observations contradict this, showing that some dumpsites were in close proximity to houses, increasing the potential impact on public health. The dumpsites were observed to not be fenced off and were open to informal workers to sort through the waste to recover items of value.

However, the interviewee (ANGED-2) stated, *"Tunisia has set a range of measures and programs to close and rehabilitate uncontrolled landfills in order to reach sustainability and the integration of waste management".* While interviewee (EHS-1), stated that since 2011, after the revolution, many controlled landfills such as Borj Chakir (which is the main landfill in Great Tunis and covers 120 hectares) have permission pending due to social protests by the people who live nearer to those landfills, which has contributed to increases in the random disposal of solid waste in open spaces in many Tunisian regions, including Great Tunis. Dridi and Khraief (2011) emphasised that Tunisia has invested in controlled landfills and transfer centres, but controlled landfills without fuel recovery are still the norm. At the same time, data collection revealed the legislation in Tunisia does not distinguish between municipal and (non-hazardous) industrial solid wastes, which leads to both types of waste ending up in the same landfill.

The representative of (EHS-2) expressed that the lack of citizen and NGO participation in waste management policies and strategies was one of the reasons for the closure of these landfills. In fact, since January 2011 and following the transformation that occurred at the political level of the country, Tunisia witnessed a substantial degradation of the environment caused by the mismanagement of waste tyre as an aspect of solid wastes, which have wreaked havoc on the urban and rural environments resulting in creating random dumpsites. In this context, the representative of (CITET) commenting on random waste dumping stated that, *"I believe it is due to weak regulations and non-enforcement of public health legislation and bye-laws".*

The (FMACM) official clarified that the post-revolutionary situation was worsened by several factors including social, financial, institutional, regulatory, environmental, etc. For example, the dissolution of the municipal and regional councils in urban and rural areas had

led to the complete abandonment of some actions that were supposed to be undertaken by these structures, like the development of waste management plans; financial issues faced by the councils; as well as, overlaps in roles within urban councils and ANGED in waste chain management.

In spite of that, the research revealed the country possesses environmental laws to encourage the sustainable management and recycling of municipal and industrial waste, but there was doubt whether the necessary measures for good application of these laws had been provided. Moreover, the Tunisian Government was often criticized for leaving the responsibility for waste management to the National Waste Management Agency (ANGED).

4.1.3. Funding For the Waste Tyre Management Service

As interviewees explained, tyre producers in Tunisia do not contribute towards the cost of the waste tyre management service. *"Currently no client pays for any waste tyre collection services, i.e. tyre producers (whether tyre importer, tyre manufacturer, car distributor, tyre garages or shops for tyre repair and replacement even do tyre consumers) do not pay any money as a contribution for collection and transportation of waste tyre recovery"* (FMACM).

A participant (Dealer-1) emphasised that *"I am a dealer I am not subject to tax related to waste collection, but we pay other taxes such as income tax or fees for renewing the licence, i.e. no direct payments are made in this regards"*. Results from the interviews confirm that no tyre producer paid for waste collection services. Moreover, the representative (CITET) stated that *"although there was no specific payment for tyre waste collection, however, there is a framework law for waste management financing related to solid waste control, management, and elimination through the application "the polluter pays" and "the producer–recovers. Obviously, this principle is one of the major principles promoted by this law (polluter pays), in order to facilitate waste management financing"*. One of the national programmes in Tunisia that has a small separate collection system for packaging waste is called ECOLEF. The system ECOLEF is a public-private partnership developed in 2008 to generate value from packaging waste. It includes 180 collection micro-enterprises (the micro-enterprises have a choice to sell packaging product to ECOLEF centres or to private recyclers direct), and operates 55 sorting and collection centres. ANGED is responsible for operating several ECOLEF centres and subsidizes plastics collection and transportation. Waste materials are then sold to local recyclers, who recycle about 70% of collected waste.

The ECOLEF system is financed by a mandatory contribution by packaging producers, and a 5% eco-tax paid on the imported plastics. The Ministry of Finance is responsible for collecting tax and financing the ECOLEF system by the FODEP fund (eco-taxes) on the importation of plastic products (including empty plastic packaging and raw material, no tax has to be paid on the importation of already filled packaging). The participant (CITET) clarified that despite this system, 76% of all waste found its way into landfills or open dumps. The main reasons were because most companies did not pay their voluntary contributions according to the approved law, as was confirmed by (ANGED-3). While (CITET) indicated that due to a decrease in the quantities collected, the budget allocated to the system had also decreased. Furthermore, the financing of ECOLEF was based on the budget proposition and according to the quantities collected by ECOLEF's system. In this context, the research revealed that according to discussion with participants the reasons for the low levels of waste plastic collection was due to barriers related mainly to the price offered by private companies that were not members of ECOLEF, which created a concurrence with the system. In some cases, problems were related to the inability of some ECOLEF points to accept the collected quantities due to non-congruence between the number of workers per point and the accepted quantities. However, ANGED was still thinking to apply the same system to waste tyres, but they were facing obstacles such as a lack of sorting and collection centres for waste tyres (EHS). The interviewee (FMACM) clarified such this system faced difficulties to be effective due to the corruption in middle administrations in terms of enforcement of laws, which affects sustainable financing. Therefore, interviewees deemed the system not worth applying to waste tyre management.

4.1.4. The Situation of Awareness and Community Participation in the Field of Waste Management

In Tunisia, there is a worrying deterioration in terms of the waste tyre as an aspect of SWM in both urban and rural areas. This situation results from the waste producers and NGOs not being involved in waste management decisions because government laws or policies have not made it possible, especially in the era of the former regime before the revolution (MESD). One interviewee (FMACM) stated that the political scene in Tunisia after the revolution of 14 January 2011 has witnessed the transition of three successive governments. Meanwhile, the National Constituent Assembly for drafting a constitution has adopted a new basis for election of municipal councils, rural and regional councils, who are responsible for waste management, so "this waiting situation has caused an impediment in the establishment

of the national programs for waste management". Besides, the interviewee (EHS-1,2) emphasised that the deterioration increased due to *"the situation of an unconscious absence of eco-citizenship behaviour and lack of citizens' responsibility in terms of disposing the waste into the environment, especially after the advent of the revolution in January 2011, which became a public phenomenon of disposing of waste randomly"*. Awareness is a critical success factor for effective participation and implementation of community activities. In this regards, the study revealed that the lack of awareness is one of the barriers to effective community participation. One interviewee (FMACM) pointed *out "the absence of awareness and communication between the government and society, led to a state of indifference, therefore, the citizens began to believe that the waste cleanliness is the responsibility of the government alone*". This result is identical to what the GIZ (2010) report indicates, in that the dynamics of "awareness, communication, and informatics after the revolution has turned into a miserable and timid situation for many reasons related to the laceration between the citizens and the administration, as well as the irresponsible behaviour of the citizens and waste producers".

The same interviewee (FMACM) explained that Tunisia after the revolution witnessed political transformations at the level of the country as this caused instability in municipalities, as a result of the dissolution of municipal councils in order to hold an election for new municipal councils and "this case contributed to creating a gap in the setup communication strategy due to the lack of experience in this field". Meanwhile, the interviewee (TOCI-1) emphasised that the ANGED did not set up "an information and communication plan adapted to the crisis". In this regard, Darwish. (2017) and Loschi (2019) stated that after the revolution, i.e. since 2011, and following the transformation that occurred at the political level of the country, Tunisia witnessed a substantial degradation of the environment caused by the mismanagement of solid wastes, which wreaked havoc on the urban and rural environments resulting in hot spots of garbage and uncontrolled dumpsites. This status leads to the outbreak of environmental protests in Tunisia and indirectly fostered the diffusion of environmental mobilization.

Therefore, punishing violators may become an urgent necessity and a duty to deal with along with the extension of the control system to restore its effectiveness in terms of transparency and social justice. On the other hand, the interviewee (CITET) highlighted that *"it is the time to focus on the awareness and education among citizens in order to encourage them to*

involve in waste management issues, and the establishment of transparency in order to promote environmental sustainability in all things".

4.1.5. Impact of Waste Tyre on the Environment

Waste products and pollution are the unpleasant price usually paid for urbanization and industrial development. The increasing pollution caused by the growing use of automobiles and other vehicles has become a cause for alarm around the world. However beneficial tyres may be to mobility, scrap tyres negatively affect the environment when improperly disposed of. In terms of the impact of waste tyre disposal on the environment and the public health, the representative of ANPE recognized the effect on soil and underground water pollution as among the biggest impacts. The ANPE officer explained:

"There are no specific landfills (as one homogeneous type of waste) to dump waste tyre that should be subject to strict in terms of design and operation. Therefore, waste tyres are dumped on open spaces or in landfills; thus the tyres disposed of in landfills tend to rise to the surface, disrupting the protective final cover of closed landfills which may cause leachate leakages during the rainy season. This could enter the water source leading to underground water pollution and soil contamination". Furthermore, the researcher's observations accorded with the findings of Mahjoub et al. (2020), who emphasised there are several different types of liquid and solid waste, such as tyre waste and other industrial compounds, that are discharged in surface water, as happened in Melian stream (seen figure 4.7). The representative of (WTRC) pointed out the lack of control of open dumpsites can have a negative impact on the environment and public health, such as the burning of waste tyres or dumping them in open space to become a breeding ground for insects and rodents. The researcher observed such tyres were dumped randomly in open spaces, which became a place of insects breeding (as seen in figure 4.8 (A&B).

Figure 4.7 Shows Waste Tyre Disposal in the Surface Water at Wadi Melian (Melian Stream)

Source: Mahjoub et al. (2020, p. 50)

Figure 4.8 (A&B) Shows Waste Tyre as a Place of a Breeding Ground for Insects

Source: The author

Interviewee (EHS-1) expressing that *"the waste tyres are of a great nuisance to the community"*. For example, the burning of tyres in Tunisia after the revolution of January 2011 became a common phenomenon as a means of protest, for the purpose of blocking roads and streets and was used as an expression of civil disobedience. Which caused a nuisance for many people because the burn of a waste tyre releases a dark and thick smoke. According to local news sources, the study revealed the burning waste tyres became a common phenomenon by protesters; for example, on December 20, 2011 young people in the neighbouring towns of Kasserine, Gafsa, and Sfax during the revolution staged protests in solidarity with Sidi Bouzid. Protestors responded to police violence by throwing stones and burning tyres in the middle of the street (Honwana, 2011). Moreover, in March 2020, the outskirts of the Tunisian capital witnessed protests over the absence of foodstuffs and commodities from stores, amid calls for a fair distribution of food in the country during the quarantine imposed to confront the Coronavirus. In this regards, in front of the residence of the Tunisian President, Qais Said, in the "Al-Manhala" area, hundreds demonstrated, burning rubber wheels, demanding a fair distribution of food baskets to the poor and marginalized classes (Al Ain News website in Arabic, [Amin] (2020, as seen in figure 4.9).

Figure 4.9 Example of Tyre Burning by Protesters

Source: Al Ain News website in Arabic, [Amin] (2020)

Furthermore, the study revealed that many of the participants stated clearly that the severity of the problems of waste tyres occurs predominantly in poor communities, especially in areas where waste removal is erratic or non-existent, therefore, they exploit any open spaces to dispose of their waste, including waste tyres. The interviewee (EHS-1, 2) expressed that *"the phenomenon of random waste tyre disposal causes a distortion in the aesthetic view of neighbourhoods and cities such this cases increased after revolution 2011".*

Observations showed the current practice of waste tyre disposal was very poor in the city of Tunis and its environs. For instance, waste tyres were observed on both sides of the road at Zaghoun region in the form of piles dumped in open spaces, whereas that is supposedly to be a public park for residents of the area, according to what one witness said (as seen in figure 4.10 - A). While the figure 4.10 – B shows piles of waste tyres dumped next to the wall of residential neighbourhoods in Bab Alkhadra area. Besides that, figure 4.10-C illustrates waste tyres on the building roofs. (OBS). This situation is aggravated by the absence of a tyre waste collecting system or designated specially constructed landfill sites in the country for tyre wastes.

Figure 4.10 (A, B and C) Current Practices of Waste Tyre Disposal in Urban Areas

C

Source: The author

To avoid the indiscriminate spread of waste tyres, the government must take care of this waste by creating a system that ensures the sustainability of transportation, collection and recycling tyres, which can help harmful chemicals stay out of the earth, water, and air. It can prevent tyres from becoming disease-carrying, pest-breeding grounds and can prevent them from starting raging fires. Thus, when the customer is ready to get rid of the old tyres, they are sure to be recycled (TOCI-2).

4.1.6. The Level of Waste Tyre Generated

As per Chapter Two, tyres are a major worldwide problem when they become waste. This problem associated with tyre waste management is not alien to Tunisia. Each year in Tunisia and elsewhere over the world, new accumulations of waste tyres are added to the already existing heap (Ajam et al., 2020). Sadly, there are no formal records or statistics on the level number of new tyres entered country or waste tyres generated in the level of Tunisia context. One of the gaps identified in the literature review was the lack of data about the levels of the waste tyres being generated and the absence of a legal framework specific to waste tyre management as well (LABIDI, 2010; GIZ and SWEEP-Net, 2014; Ayadi, 2015). This is what has the representative of (CITET) and (ANGED-1) emphasised: that the government lacks any statistical data of waste tyres generated, whether that is stockpiled in official or unofficial dumps, stored or even abandoned. It observed that this is an obstacle to knowing the fate of ELTs and planning the introduction of a legislated recycling process of ELTs.

This corresponds to what confirmed by Chaher et al (2020) that the major challenges in the case of Tunisia are the lack of operational enforcement, financing, public awareness, trained staff, reliable data, and basic know-how. Therefore, without a reliable flow data regarding the stockpiling of waste tyres at landfills, therefore, it might be difficult to design sound strategies for waste tyre management. Thus, the estimation of the waste tyre generation that flows in the country is considered as a required factor, which assists the decision-maker in future to assist the planning of a product charge and design of an effective subsidy program; both are important to the successful operation of the waste tyre-recycling programme. In this regard, the researcher proposed a methodology capable of predicting an estimate of waste tyres generated in the period of time between (2008-2012) by using the number of vehicles registered on the road (as stated on the methodology section 3.9.3.2.), according to statistical data. The statistical data collection stage of the research process is of essential importance, as the analysis from which all conclusions are reached may be influenced by the type and quality of data collected. In this regard, the following data have been collected in order for this research to provide responses to the objective that it seek to address: statistical data of vehicles registered on the road in order to quantify the number of waste tyres generated in Tunisia. This will enable a comprehension of the number of waste tyres that the country has to dispose of. Substantial amounts of secondary data have been derived from the Technical Agency for Land Transport (TALT) and National report on the state of Environment about the number of vehicles registered on the road.

Table 4.2 shows the category and number of vehicles registered on the road on the period between (2008-2012) in Tunisia. Tunisia is home to some 1.6 million registered road vehicles. Table 4.2 shows that the number of vehicles increased over these years, reaching their peak in 2012, with Tunisian roads busier than ever before. As is noticeable, passenger cars constituted the majority of vehicle types and they were the fastest-growing category. CEDARE (2015) emphasised that in 2013, 67% of all motorised vehicle types were private cars, and the total stock close to one million that year. The reasons for the growth of the ownership of passenger cars in Tunisia compared to other vehicles was due to the availability of loans for the purchase of cars, and other fiscal and financial facilities (Mraihi et al., 2013), with low-interest rates for car loans provided by the government in the 1990s together with increasing incomes (Abbes & Bulteau, 2018).

Table 4.2 Number of Vehicles Registered on the Road for the Five-Year Period Between (2008-2012) According to the Available Data

Period (Year)	Passenger Car[4] (Private cars)	Light commercial vehicles[5]	Heavy Trucks [6]	Tractors	Others	Total
2008	772,315	320,826	75,189	128,720	14,640	1,311,690
2009	810,931	336,868	78,949	135,156	15,372	1,377,276
2010	851,478	353,711	82,897	141,913	16,141	1,446,140
2011	894,052	371,397	87,041	149,009	16,948	1,518,447
2012	938,755	389,967	91,393	156,459	17,795	1,594,369

4.1.6.1. Estimation of Waste Tyres - Methodology

The methodology of Methods I & II was based on assumptions and estimations to quantity inventories of waste tyre generated in Tunisia during five years (2008-2012), according to data of the number of registered passenger cars on the road.

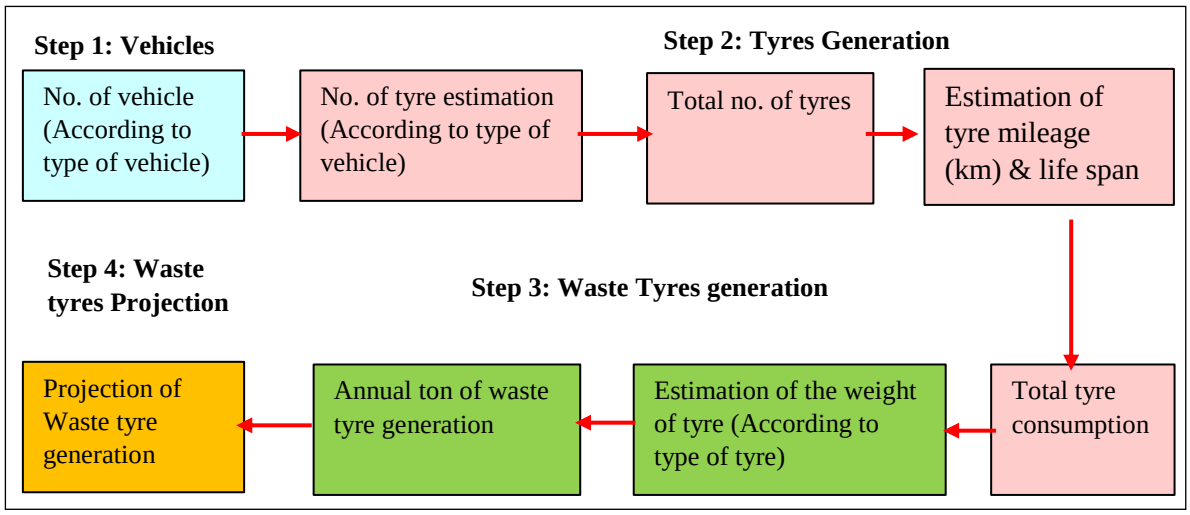
The study at this stage to estimate the quantity of waste tyres expressed by number (unit) and by weight (tons) generated in a specific category (private cars/passenger cars) in Tunisia. These data were consolidated for an integrated analysis in order to contribute to the development of a model of waste tyre management.

It is important to note that all data used in the assumptions in terms of lifespan and travelled distance is as an average for all tyres. While the ranges can be used for tyre waste arising in between two models (Methods I & II) and statistical uncertainty has to be taken into account in both models. This implies uncertainty over the lifetime of a tyre, and the exact date when the tyre becomes a scrap tyre is only an estimation. Composition of tyres changes over time and therefore only mean values can be used for simulation. Furthermore, seasonal tyres like summer and winter tyres vary in their composition as well (Phillips, 1998; Pehlken and Müller, 2009).

The proposed method I for the average estimation of waste tyres inventories generated is illustrated in Figure 4.11 below:

[4] Passenger cars are motor vehicles with at least four wheels, used for the transport of passengers, and comprising no more than eight seats in addition to the driver's seat.
[5] Light commercial vehicles are motor vehicles with at least four wheels, used for the carriage of goods. Mass given in tons varies between 3.5 and 7 tons.
[6] Heavy trucks are vehicles intended for the carriage of goods. Maximum authorised mass is over the limit of 7 tons.

Figure 4.11 Method I The estimation of tyre generation for five years (2008-2012)



Source: The author

Method I: Estimation of passenger cars waste tyres generated using the number of Passenger Cars Registered, Distance Travelled and Tyre Life

This method takes into account the number of passenger cars registered with the Technical Agency for Land Transport (TALT), Tunisia, the average distance travelled and the economic life of tyres. Table 4.3 shows the estimation of waste tyre generated using this method. The total annual waste passenger cars tyre generated was 1,581,061 units.

Based on the estimated waste passenger cars tyre arising, Table 4.4 shows the total annual weight (in tons) of waste tyres generated.

Table 4.3 Estimation of Waste Car Tyres in 2012

(A) Type of Vehicle	(B) No. of vehicles registered as at 2012	(C) Tyre per Vehicle	(D) Total No. of tyres (B) × (C)	(E) Est. average distance travelled (km/year)	(F) Tyre lifespan (km)	(G) Total tyre consumption (Units) as at (2012) (D)×(E)/(F)
passenger cars	**938,755**	**4**	**3,755,020**	**20,000**	**47,500**	**1,581,061**

A & B - Number of passenger cars registered on the road for the past five years (2008-2012) obtained from the Technical Agency for Land Transport (TALT).

C - Number of tyres on the road per vehicle.

D - Total number of tyres on the road (usage).

E - Estimation average distance travelled (km/year)[7]

F - The estimation average of the tyre lifespan driven by Van Beukering and Janssen (2001), Pehlken and Müller (2009).

G - Tyre consumption estimated = waste tyre arising or generated

Based on the estimation of waste passenger car tyres arising, Table 4.4 shows the total annual weight (in tons) of waste tyres generated.

Table 4.4 The Estimated Annual Weight (in Tons) of Passenger Car Waste Tyres Generated

Vehicle type	(G) Tyre consumption (Units)	(H)[8] Weight/Unit (Kg)	(I) Total weight (Kg) (G)×(H)	(J) Annual tonnage (I)/1000
Passenger car	**1,581,061**	**7**	**11,067,427**	**11,067**
Total				**11,067**

Method II: Estimation of passenger car waste tyres generated using tyre replacement factor. The field survey gathered the replacement factor (multiplier) based on an interview with a businessperson (Dealer-2), representative of one of the tyre trademarks (previously he worked for Tunisian Tyre Industries Company [STIP]), who stated that the annual replacement factor for tyres by motorcars in Tunisia is 1.3 tyres per passenger car per year. In this method, the total number of passenger cars registered (Technical Agency for Land Transport [TALT]) in 2012 is used as a base to calculate waste tyres arising. The tyre replacement factor would indicate the number of tyres replaced annually, hence the waste tyres arising.

The replacement factor varies from country to country. For example, the replacement factor in America for the national average is one used tyre a year from each motor or passenger vehicle (Steward, 2012). Whilst in Europe, the replacement factor for the tyres is estimated between 3.5 years or 30,000 km and 6 years or 80,000 km, which depends on the mechanical

[7] The estimation of annual average distance travelled for passenger car were cited according to the report released by the United Nations Development Account (UNDA) project to assess the transport CO2 emissions and to evaluate potential policies to mitigate them. Tunisia was one of the pilot cases in this project. The information of annual average distance travelled was obtained through household/travel surveys (UNECE, 2013).

[8] Average weight of waste tyres for passenger cars (Sienkiewicz et al., 2012, p. 1743). Vehicles tyres vary in size, type and other parameters, and that's why the average weight of vehicle tyres are taken in consideration with the number of tyres fitted on the vehicle when calculating the average of waste tyre generated. For example, the tyre weights can be anything between 6.5 and 80 kg for a truck tyre.

load (Pehlken and Müller., 2009), i.e. 3.5 years if divided by four tyres is equal to 0.875, which is near to one used tyre a year from each motor vehicle. Therefore, the researcher found the replacement factor 1.3 in Tunisia is a logical factor if taking into an account the weather and road conditions in Tunisia, where the climate is a hot-summer Mediterranean climate (Köppen climate classification CSA) in the north, and where winters are mild with moderate rainfall and summers are hot and dry. Temperatures in July and August can exceed 40°C when the tropical continental air mass of the desert reaches the whole of Tunisia (Nation Institute of Meteorology Tunisia, 2017). In line with this, Ntziachristos and Boulter (2003) pointed out the weather and road condition affect the lifetime of a tyre. Wet conditions decrease friction, and hence should be expected to decrease the wear rate. In addition, if the tyres smuggled into Tunisia are taken into consideration, which as was revealed in this study are poor quality products that have a short lifespan, but which find their way into the market in Tunisia, wherein smuggled tyres represent 70% of tyres imported, as stated by Ayadi (2015).

Accordingly, the equation utilised to figure out waste tyre arising using replacement factor was as follows: Total No. of Passenger Cars Registered on Road x Tyre Replacement Factor = Waste Tyre Arising (as of 2012), as illustrated in Table 4.5

Table 4.5 The Waste Tyres Arising Based on Method II

Vehicle Type	**(A) No. of vehicles registered as of 2012**	**(B) replacement factor in Tunisia is 1.3**	**(C) Waste tyres arising (unit) (A)×(B)**	**(D) Annual tonnage (C) × 7 kg[1] /1000**
Passenger car	938,755	1.3	1,220,381	8,542
Total			**1,220,381**	**8,542**

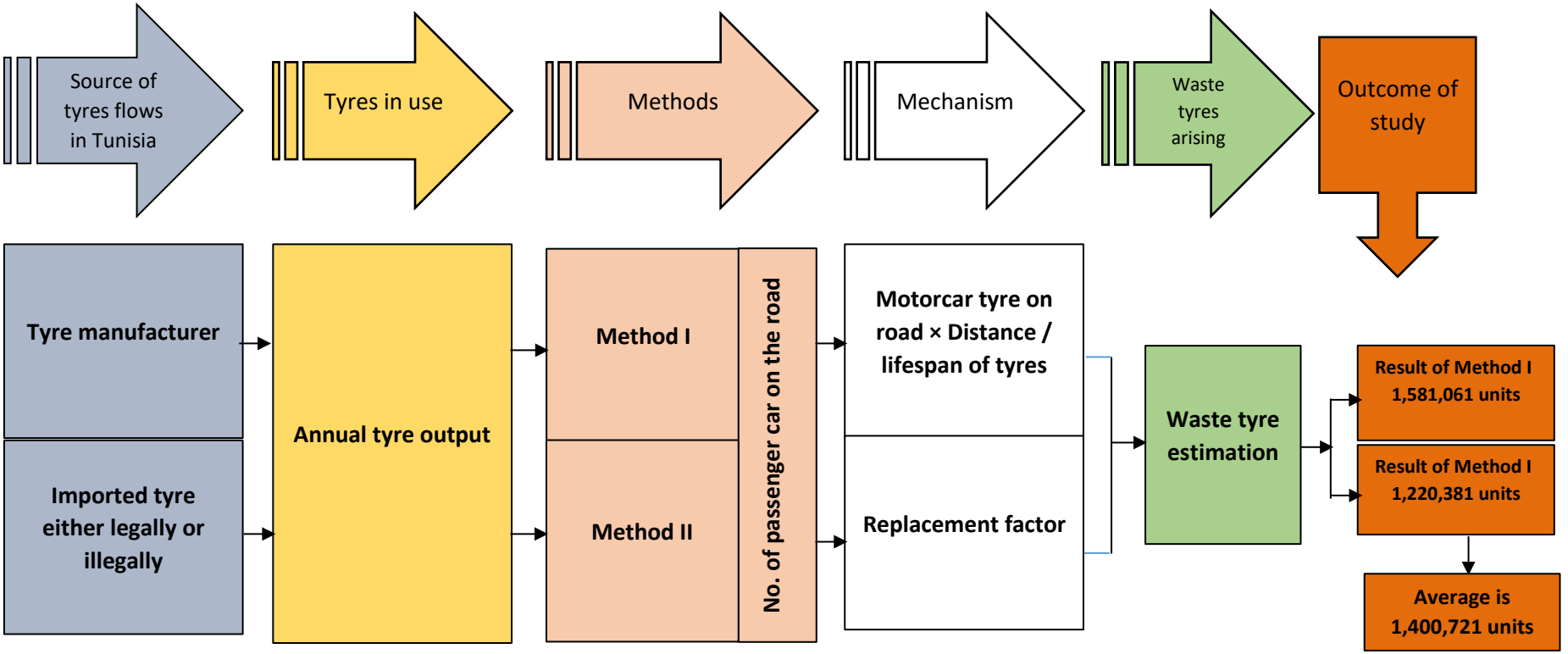
[1] Average weight of scrap tyres for passenger car

Source: Sienkiewicz et al. (2012, p. 1743).

Although there is a difference in terms of methodology between methods I and II about the estimation of waste tyres arising in Tunisia, the results are fairly close to each other, ranging from 1,220,381 to 1,581,061units/tyre. Therefore, the results of the estimation average (in tons) of the waste tyres arising in Tunisia based on methods I and II are summarised in Figure 4.12.

According to the estimation (as illustrated in figure 4.12), the average waste tyres generated was about 1.4 million waste tyres, which eventually entered the waste stream, representing a major potential waste and environmental problem in the context of Tunisia.

Figure 4.12 Estimation Average of Waste Passenger Car Tyres Arising (Methods I and II)



Therefore,

Waste tyres arising in tons = $\frac{1400721 \text{ units} \times 7 \text{ kg as an average weight of tyre}}{1000}$ = 9,805 tonnes

4.1.7. The Institutional Framework and Legislation or Legal Framework Governing the Management of Waste Tyres

4.1.7.1. Current Regulations and Policies on Waste Tyre Management

Waste management has always been one of the strategic pillars of the policy of the government in Tunisia. The future vision is to improve the framework and protect the environment. Since the late 1980s, the Tunisian government has enacted many laws and decrees to protect the environment and to manage and mitigate pollution in general and more particularly, to promote the sustainable management of waste, which with economic development is becoming a concern for the regulator as it can endanger both the human and the natural capital of the country. Dridi and Khraief (2011) expressed that the protection of the environment generally and waste management particularly, is currently a priority in Tunisia, to the extent that investments in environmental protection had reached 1.2% of GDP. In this context, the interviewee (MESD) clarified that Tunisia had been concerned with the environment since independence, but the pace of attention to legal issues and regulations had increased since 1988 with the creation of the National Agency for Environment Protection (ANPE). In 1991, Tunisia created for the first time a Ministry for the Environment. Besides that, the participants (MESD) and (ANGED) stated that Tunisia had ratified many important multilateral environmental agreements to promote environmental protection, such as the Kyoto Protocol and the Basel Convention.

The interviewee (MESD) stated, *"One of the most important institutions affiliated to the ministry of environment that had a direct relation with waste management is the National Waste Management Agency (ANGED)"*, which was established by Decree No. 2005-2317 of 22 August 2005. Prior to this, in 1995 a framework law on waste management was promulgated. However, this framework law for waste management did not include provisions for waste tyres specifically. The interviewee (CITET) emphasised that the time of data collection in Tunisia, *"there is no specific legislation controlling waste tyre disposal"*. Waste tyres in Tunisia are considered to be a non-biodegradable solid waste. Although most of the waste tyres are disposed of in dumpsites or in open areas, the same interviewee said: *"There is no specific regulation to regulate waste tyre in terms of collection, transportation or recycling"*. The main law which controls waste management and disposal is the law 1996-41; this is the Organic Law of Commons entrusting waste collection in the communal areas to municipalities, as represented in the law 1975-33. There is also decree 726-1989 relating to rural councils entrusting waste disposal in rural areas to elected councils. According to

law 1996-41 concerning waste management and disposition, this law addresses the management of all types of waste without mentioning waste tyre management more specifically, or the principles applied to the ELT. The concept of waste, in accordance with law 1996-41, is explained in chapter 2: Waste is all materials and things disposed of by the holder or intended to be disposed of or that need to be disposed of or to be removed, according to provisions of this law. Therefore, Tunisia has not defined an approach for tyre waste, i.e. for ELT (Legislation Portal Tunisia, 2015).

Besides, the representative of the (ANPE) indicated in the interview there is a set of texts that strengthened the regulations indirectly related to waste tyres that represents environmental protection and the fight against pollution, including namely Law No. 95-70 on the conservation of water and soil and Law No. 2007-34 on air quality. He continued, saying that *"despite the existence of this law, it did not prevent the air, water and land of Tunisia from being polluted"*. This is due to the lack of enforcement of the law or the lack of follow-up by the competent authorities to execute this law. On the other hand, the interviewee (ANPE) admitted that despite the comprehensive legislative framework for waste management, this legislation did not refer to the obligations that must be followed by tyre waste producers or distributors to regulate the waste collection process and recycling requirements. In addition, not clarifying the division of roles between stakeholders and those involved directly or indirectly in tyre waste to manage it in a proper way. It was observed that the activity of tyre dealers in Tunisia involved only the selling, repairing or fitting of tyres, limiting the accomplishment of environmentally sound objectives (OBS).

Moreover, the interviewee (Dealer-10) stated, *"We as a distributor have no legal requirements to educate the general people about the problem of waste tyre management and we are not required to establish waste tyre collection logistics"*. Through the interviews with participants, it was found that there were no tyre collection centres created to accept and temporarily accumulate waste tyres disposed of by garages, shops or tyre distributors. Meanwhile, the participant (TOCI) clarified that the distributors were not under obligation to receive waste tyre when they sold new ones to the consumers. Therefore, this represents a huge obstacle to the behaviour change of consumers. In this regard, consumers are playing two roles in the life cycle of tyre waste: that of a customer and a tyre waste holder. That is why the tyre waste management system cannot be efficient if consumers are not actively involved in it. They cannot contribute if they have no environmental awareness and information about it. Wilson (1996) underlined that Waste minimization from the source

requires changes in the behaviour of people, either collectively or individually. Whatever policy measures are utilized, they will require support with coordinated information campaigns, both to advise people what they are required to do and to persuade them to do so.

4.1.7.2. The Institutional Framework in Tunisia

The government of Tunisia have various institutions involved in the management of waste; the National Agency for waste management (ANGED); and the local municipalities. They are both responsible for collection, transportation and disposal of waste. The central government, through the Ministry of Environment and Sustainable Development, formulates waste management policies. However, the government have not adequately assumed full responsibility the waste tyre management as a subject of great environmental importance and has not introduced any approach that established the norms applied to waste tyre management, with the objective of waste prevention, development of collection activities and involvement in environmental actions of tyre stakeholders. Participant (FMACM) stated *"….the waste is collected by the municipalities and contracted private sector companies. The government has not established waste tyres prevention, developed separate waste tyres collection systems and proper waste tyres treatment and disposal system. Only plastic, paper, glass, scrap metals have a noticeable recovery level, but with very limited recovery and recycling activities for waste tyres. The collection of the waste tyre is driven by informal collectors from disposal sites".* Looking at these results, the policies in Tunisia do not extend any responsibility to tyre producers or retailers, suppliers and distributors for end-of-life tyres or suggest the establishment of a non-profit organization responsible for the management of those waste tyres. The participant (FMACM) indicated that no policy approach defined the disposal target of waste tyres; there was only policy defining broad approaches for management and handling practices of all the waste streams, without defined disposal targets or supporting or guaranteeing effective treatment options for the waste tyres. On the other hand, interview with another participant (CITET) indicated something noteworthy about the management of waste in Tunisia; namely the overlaps in roles suffered within urban councils and the ANGED in waste chain management, which was hampering the sector from achieving the objectives set during national actions and strategies.

The interview with the participant representing Former Member of Al Zahra Council Municipal (FMACM) stated that *"the tyres distributors, suppliers, garages and scrap dealers have not maintained any aspect of cooperation with other stakeholders, such as*

municipalities and regulators, to deal with specific environmental problems regardless of whether there is an economic incentive model for recovery and recycling activities of waste tyres". He continued by saying: *"As I told you, the decisions and responsibilities of waste tyres are left to consumers or waste tyre producers, either it was stockpiled illegally or disposed it of indiscriminately and abandoned in the environment".* Moreover, there were no established partnerships for creating a waste tyre society and developing technical and economic aspects in the management of the waste tyre practice. There were no established management mechanisms, including material and auditing flows as well as inspecting and administrating system for waste tyre management.

4.2. Results of Section Two:

4.2.1. Introduction

This chapter presents the results of the systematic review of selected studies for waste tyre disposal options in order to synthesise the best available evidence on the sustainable applications that are beneficial to the environment from an LCA perspective.

4.2.2. Results of Research Strategy

A total of eight peer reviewed journal articles were included in this study for analysis, as illustrated in Table 4.6. The included articles were extracted from different databases as follows: Web of Science, All database, Science Direct, Google Scholar and SCOPUS, as presented in Table 3.4.

The studies that have been included for analysis comprised eight studies from peer-reviewed journal articles (see Table 4.6). These articles focus on LCA of ELT management, and these extracted studies are limited to the period of 2008-2017 and include different kinds of tyre waste treatment technologies in different geographic locations, distributed on three different continents as described in paragraph 4.2.3.

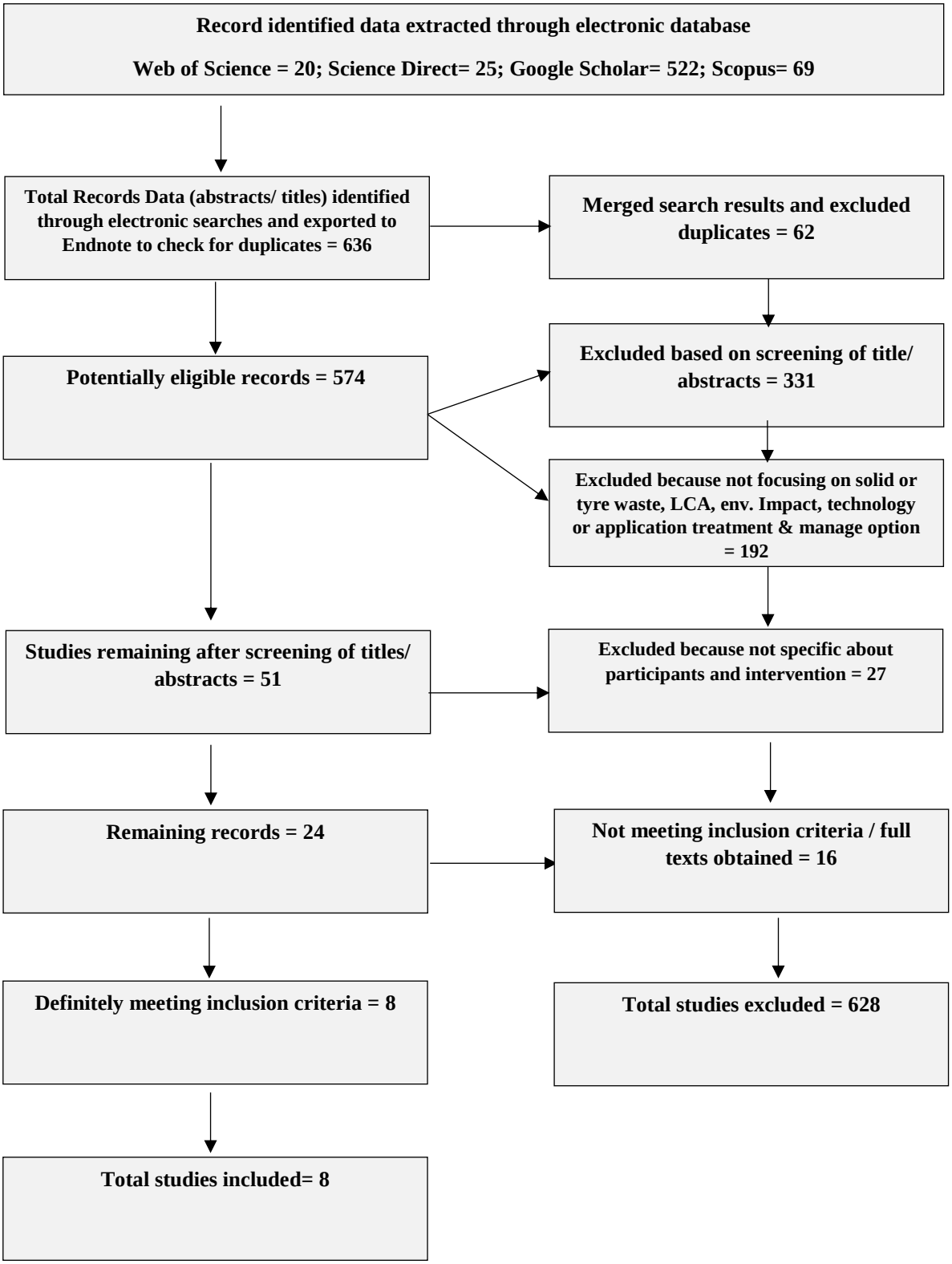
Table 4.6 Source Database for Each Study Extracted

No.	Author & year of publishing	Source Database
1	Li et al. (2010)	Waste Management/ Elsevier
2	Li et al. (2014)	LCA of Waste Management Systems
3	Sun et al. (2016)	International Journal of Life Cycle Assessment
4	Fiksel et al. (2011)	Clean Technologies and Environmental Policy/ Springer
5	Feraldi et al. (2013)	LCA of Waste Management Systems
6	Ferrão et al. (2008).	Waste Management
7	Clauzade et al. (2010)	Life Cycle Management
8	Ortíz-Rodriguez et al. (2017)	Energies

4.2.3. Selection of Included Studies

The selection of the included studies commenced with the retrieval of 636 records that potentially described LCA or environmental impacts of waste tyres between years 2006 to 2017. All the records retrieved were exported to EndNote to be verified and managed effectively. The 636 records were retrieved from the different databases as follows: 20 records from Web of Science; 25 from Science Direct; 522 from Google Scholar; 69 from Scopus. The search results are presented diagrammatically, as shown in Figure 4.13.

Figure 4.13 Flowchart for Search Results for Data Extracted



(Source: The author)

4.2.4. The Outcomes of Selected Studies for Final Tyre Disposal Technologies and their Environmental Impact from a LCA Perspective

This part presents the extracted and summarized different treatment technologies for waste tyres that have been selected from studies. In this regard, the papers developed in relation to the end-of-life tyre destination that used the LCA were grouped by continents, in order to determine management options towards tyre waste disposal that are the most beneficial alternative from an environmental standpoint. In the same context, the studies were reviewed in terms of their environmental impacts, which are included in each study to identify the impact categories have been covered and/or have been missed when conducting LCA for waste tyres. The data extracted from the selected studies are presented and summarized in Table 4.7.

Table 4.7 Summary of Treatment Technologies and Environmental Impact Categories Based on the Selected Studies

Author, year, location	Technologies treatment participants	Software database & Methodology used to evaluate environmental impact	Impact categories considered																							Outcomes of Main findings
			acidification	nitrification	ecotoxicity	radiation	carcinogenic effects	global warming / climate change/	inorganic	organic respiratory	ozone depletion	eutrophication	tropospheric ozone (smog) formation	human health cancer effects	human health non-cancer effects	abiotic depletion	human toxicity	marine aquatic	Total primary energy consumption/ energy demand	non-renewable resources	Water consumption	fossil fuels	minerals	land use	iron ore	
Li et al. (2010) **China**	Ambient grinding, devulcanisation, pyrolysis and illegal tyre oil extraction	GaBidatabase / Eco-indicator 99 Method.	x	x	x		x	x	x	x												x				The most eco-effective ELT treatment technology is pyrolysis, followed by dynamic devulcanization, ambient grinding and illegal tyre oil extraction.
Li et al (2014) **China**	Recycling scrap tyre to produce ground rubber through three steps: rubber powder preparation, devulcanisation, and refining.	ecoinvent database/ Eco-indicator 99	x	x	x	x	x	x	x	x	x											x	x	x		The most eco-effective recycling process to produce ground rubber that executed in three steps, where the process of rubber powder preparation is greatly beneficial to the environment, followed by refining, and then devulcanization.
Sun et al., (2016) **China**	Recycling to produce reclaimed rubber	SimaPro 8 (RCEES[9] and Ecoinvent 3 databases)/ CML Method	x					x		x		X					x									The most eco-effective stages indicate that recycling to produce reclaimed rubber provides greater impact reductions than the other stages from the acquisition of raw materials to the production and use.
Fiksel et al. (2011). **USA**	Cement production, civil engineering, incineration, industrial boiler, tyre shredding and crumb production, artificial turf, moulded products, asphalt production, retreading.	NREL or SimaPro databases/ TRACI Method	x		x			x			x	X	x	x	x											The most eco-effective applications represent in artificial turf, followed by energy recovery (co-processing in cement kilns and energy generation).
Feraldi et al (2013). **USA**	Mechanical recycling by ambient-temperature and energy recovery by co-incineration at a cement kiln	Traci Method	x					x		x		X	x						x						x	The most eco-effective treatment technology indicate that the material recycling scenario provides greater impact reductions than the energy recovery scenario. Thus, considered more favourable option in terms of the waste management hierarchy.
Ortíz-Rodríguez et al (2017) **Colombia**	Reuse and retreading, incineration, Grinding (recycling)	Ecoinvent V2.01 database/ CML-2001 Method	x					x			x	X	x			x	x									The most eco-effective treatment technology indicate that the incineration of whole tires in cement plants, and the activities of grinding and floor manufacturing from granulated rubber, exhibited the best indicators, especially in terms of environmental load avoidance through the recovery of materials.
Ferrão et al. (2008) **Portugal**	Retreading, recycling, incineration (cement kiln and power plant) and landfill	Ecopoint / Eco-indicator 99	N/A																							Retreading is the most cost-efficient alternative in terms of the recovery of material and energy
Clauzade et al. (2010). **France**	Destructive methods (cement works, foundries, steelworks and urban heating) and five non-destructive methods (retention basins, infiltration basins, moulded objects, synthetic turfs and equestrian floors)	N/B	x		x			x				X	x						x	x	x					The environmental assessments show regardless of the recovery method studied, and regardless of the impact focused on, the management of ELT provides, in most cases, a significant environmental benefit

Green colour represents the covered impact categories in each study for different waste tyre treatment technologies.

Red colour represents the missing impact categories in each study for different waste tyre treatment technologies

[9] Research Centre for Eco-Environmental Sciences of the Chinese Academy of Sciences based on SimaPro software.

The LCA studies were grouped by continents in order to understand the state of the highest level of treatment technologies achievement to date in relation to the end-of-life tyre destination that is most beneficial to the environment from a LCA perspective. Undoubtedly, these studies are going to provide the best available pieces of evidence in terms of sustainable treatment technologies for the final destination for end-of-life tyres, as this may have a viable long-term implication for Tunisia.

4.2.4.1. Asian LCA Studies

Li et al. (2010) studied four different ends of life tyre treatment technologies using LCA to analyse the process of mechanical pulverization, regeneration, pyrolysis, and oil extraction. As within the studies mentioned above, the functional unit was one metric ton of tyres. According to Eco-indicator 99, disability-adjusted life years (DALY) were utilized to assess human health-associated impacts. The impact of one unit on this weight scale corresponds to the loss of 1 year of life. Meanwhile, the unit utilized for ecosystem quality was the potentially disappeared fraction (PDF) of specie, in the form of PDF*m2*yr (where m2 is an area in square meters and yr, a year). An impact value of one for this unit indicates that all species within one square meter disappear throughout a year. Regarding the resources category, the unit utilized was Megajoule (MJ) of superfluous energy, where an impact value of one indicates that an area previously utilized to extract resources requires one MJ of additional energy in order to be utilized again due to the decrease in the availability of the natural resources (Goedkoop and Spriensma, 2001).

In the current study the following impacts were considered, which were represented in: ecotoxicity, acidification and nitrification, emission of carcinogenic materials, warming potential, emissions of inorganic and organic materials harmful to human health, and therefore the consumption of fossil fuels. Global warming is caused mainly by the emission of CO2, CO, N2O, and CH4. In this study conducted by Li et al. (2010), it was discovered that only the oil extraction process caused negative impacts. By contrast, the process of mechanical pulverization and pyrolysis obtained the best environmental performance.

The impacts evaluated in the ecotoxicity category were those in relation to the levels of heavy metals and aromatic compounds in soil or air. Over again, oil extraction had the most negative impact as carbon is burned for energy. In terms of fossil fuel consumption, all processes were negative as no virgin materials were needed, eliminating the need for energy consumption during extraction. Even when extracting the oil (in oil extraction), the fuel consumption is averted, as the generated oil is a source of energy (Li et al., 2014). The

management option that was dominant within the Chinese end-of-life tyre marketplace was the production of floor rubber for regeneration (Li et al., 2014).

In order to enhance the overall environmental performance of floor rubber production, (Li et al., 2014) made a sequence of technical suggestions primarily based totally on the Eco-indicator 99 method. The process comprises three predominant stages: floor rubber preparation, regeneration, and refining.

According to Li et al. (2014), respiratory inorganics gained the utmost severe results, that is, the highest prorate contribution between the other categories of impacts assessed. In relation to regeneration, devulcanization accounted for most of the environmental loads, which were equal to 66.2% of the total impact. Furthermore, ameliorations of the flue fuel gas treatment contributed to better performance. Utilization of renewable and clean energy can enhance environmental overall performance by around to 22%. These outcomes can be used as a guideline to reduce the environmental load while producing floor rubber from worn-out tyres.

Furthermore, increasing energy efficiency, utilizing clean energy, and ameliorating environmental protection equipment represented effective measures to fulfil this goal (Li et al., 2014). Nevertheless, in relevance to the Chinese tyre market, Sun et al. (2016) assessed the environmental impacts of the passenger vehicle tyres. The authors utilized the CML method in order to analyse raw materials extraction, tyre production, use, and end of life. However, they also took into consideration only five out of eight impact categories, specifically global warming potential (GWP), acidification potential (AP), photochemical oxidant creation potential (POCP), eutrophication potential (EP), and human toxicity potential (HTP), since these are less difficult to explain as they are based on direct emissions that are straightforward to correlate, in addition to being more vital to tyre production. It had been assumed that all end-of-life tyres were collected and recycled and that, once the various tyre components were separated, the rubber was fully regenerated to substitute artificial rubber. This recycling and recovery process only showed negative impacts for GWP, EP, and HTP, which means that they prevent emissions rather than cause them. However, the main environmental impacts determined at some stage in the production of reclaimed rubber and waste treatment were for AP and POCP (Sun et al., 2016).

4.2.4.2. American LCA Studies

In North America, Fiksel et al. (2011) studied different applications for scrap tyres to compare the environmental benefits. The treatment application included fuel replacement, energy generation, retreading, and mechanical grinding. The grinding process analysed was aimed toward the appliance of rubber in civil construction (as asphalt and a base for artificial turf) and as a filler in new products. The authors discovered that the use of waste tyres as raw material for artificial turf was the most promising alternative, followed by recovery of energy (co-processing in energy generation and cement kilns). In spite of the study being conducted in a country where the market for artificial turf was saturated, they concluded that the recovery of energy was currently the most viable alternative option.

In the USA, Feraldi et al. (2013) studied two different final destinations for tyre treatment applications, represented by grinding and energy recovery. The authors utilized the TRACI method and analysed the future anticipation for tyre disposal by taking into consideration the changes in the USA energy matrix. The outcomes of the study identified that grinding was the ideal final destination, given that the energy recovery involves a combustion process that causes emission of harmful compounds. Concerning future prospects, the authors concluded that the lowering in the impacts of each process might be negligible.

In Colombia, Ortíz-Rodríguez et al. (2017) studied three different alternative options of ELT treatment applications utilizing LCA to estimate the environmental impacts. The first option was the reuse and retreading; the second option was incineration, and the third option was grinding to obtain new products. Grinding to produce flooring and rubber incineration in cement plants displayed the best environmental results, because it prevented harmful effects caused by recovering materials. Comparison between recovery and disposal processes for waste tyre indicated that the retreading and therefore the production of multipart asphalt presented the worst environmental performance. The performance environmental categories that were used in this study were global warming potential, ozone layer depletion, acidification, abiotic resource depletion, and photochemical ozone formation. Fuel consumption was the largest contributor to the recovery process phases, the initial production of artificial rubber, and conversion into liquid asphalt (Ortíz-Rodríguez et al., 2017).

4.2.4.3. European LCA Studies

In Europe, Ferrão et al. (2008) conducted an LCA of a new tyre, whose life cycle stages were production, distribution, use, disposal, collection of the used tyre, and recycling. The aim of this study was to assess the impacts of a new tyre during its life cycle in addition to four ways of recycling (retreading, recycling, incineration as fuel replacement in cement kiln, and incineration for energy generation) and disposal in a landfill. The Ecopoint method was adopted, and therefore the functional unit was a metric ton of used tyres. The outcomes indicated that the most relevant stages in terms of environmental impacts were tyre use. This was prospective because fossil fuels are the prime fuel consumed throughout tyre use and have a considerable impact on the environment. Despite its impact, this stage is essential in making certain the protection and guarantee the safety of the vehicle, for the reason that the greater the friction between the tyre and the ground, the more secure the vehicle is; however, the more fuel it will consume (Ferrão et al., 2008). Impacts on account of landfill disposal are especially associated with the leaching of metals, stabilizers and plasticizers, which can be mixed with the rubber for the duration of tyre manufacturing. Retreading is considered as the most cost-efficient alternative in terms of energy and material recovery (Amari et al., 1999). In spite of the fact that energy is consumed throughout retreading, the amount consumed is 2.3 times bigger whilst producing a new tyre. A critical advantage of recycling is that it prevents the usage of virgin raw material (Ferrão et al., 2008). Burning entire tyres to generate energy means they no longer require grinding. However, an advanced burning system is needed to permit the usage of high temperatures at particular points, and emissions should be kept within the range of allowable limits (Jang et al., 1998). Pyrolysis is a treatment of waste tyres that generates three different products, namely: gas, raw petroleum, and carbon black. The energy potential of gas and oil (utilized to replace fuel) is much like that of traditional products (Galvagno et al., 2002). According to Van Beukering and Janssen (2001), the greater advantage of energy generation in cement kilns is that it does not produce solid waste and also the Sulphur emissions are not a serious drawback due to the fact the Sulphur generated is incorporated into the gypsum, which is added to the last final product.

Clauzade et al. (2010) studied nine different ELT treatment applications. The author used LCA to assess used tyre as a replacement for various materials in a range of applications, including as a substitute for filler in retention basins (concrete and polyethylene blocks) and infiltration (gravel substitute); as a filler at steelworks and foundries (to complement steel), in artificial turf (instead of ethylene propylene diene copolymer–EPDM), for equestrian

floors (to replace sand), and in moulded objects (instead of polyurethane); and as fuel for urban heating (coal substitute) and in cement plants (to substitute raw materials and fuel). In this regard, the authors concluded that reusing rubber as a filler for artificial turf and moulded objects provides the greatest environmental benefits. According to the papers presented above concerning LCA for waste tyre treatment, waste tyre disposal has been shown to be of great interest in Asia, Europe and America, as a means of contributing to the decision-making process in selecting the best technological alternative from an environmental standpoint. These studies show alternative options for recycling and different applications and recycling techniques. This may encourage Tunisian decision-makers to conduct LCAs for their product if applicable. However, these technologies differ in their environmental performance, as discussed in the next chapter (in particular, see para. 5.2).

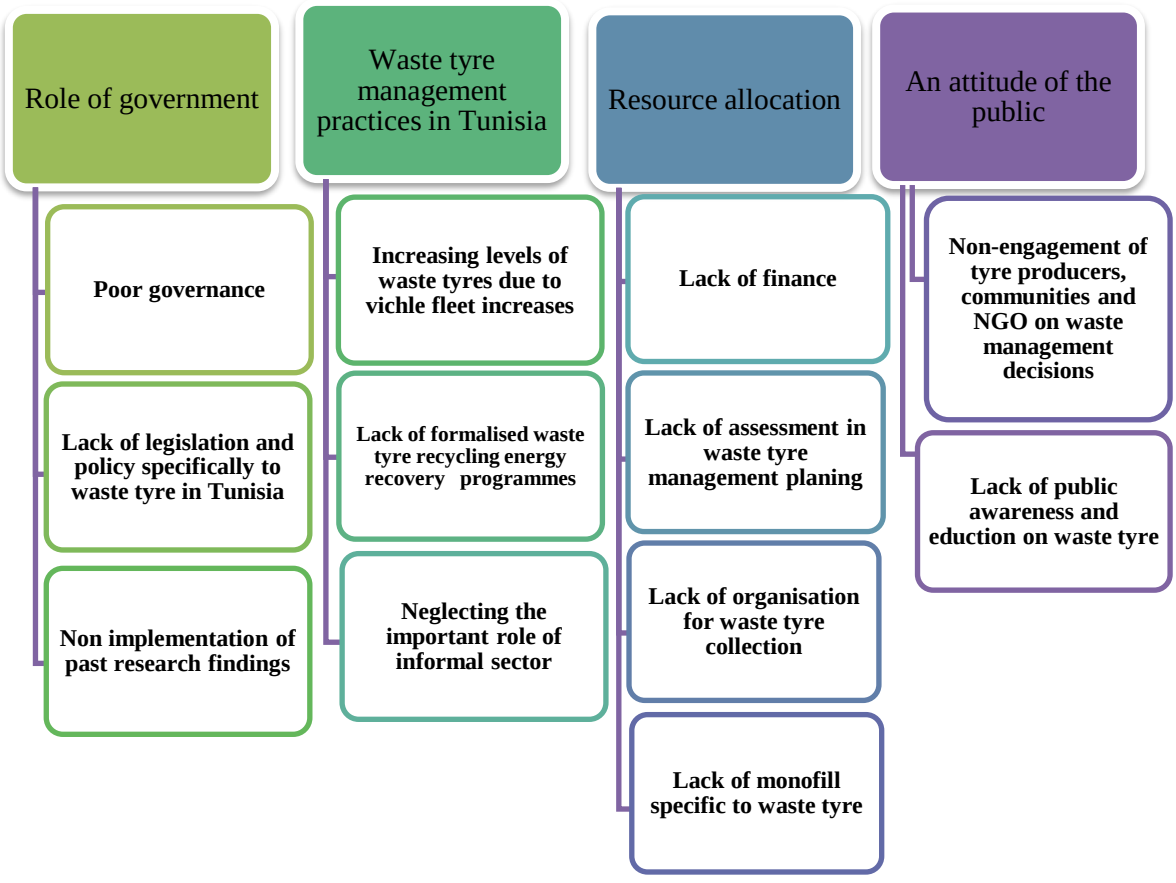
CHAPTER FIVE: RESEARCH DISCUSSION

5.0. Discussion

5.1. Challenges to Sustainable Waste Tyre Management in Tunisia

Results of data gathered from fieldwork observation and interviews show that the study area faces numerous challenges to sustainable management of waste tyres. These have been classified into four significant themes as set out in Figure 5.1 - the government role, waste tyre management practice, resource allocation, and the attitudes of the participants towards tyre waste. Each theme and related subthemes are subsequently discussed in the accompanying segments.

Figure 5.1 Identified Challenges to Waste Tyre Management in the Level of Tunisia



Source: The author

5.1.1. Role of Government

5.1.1.1. Poor Governance

Poor governance is the inability of the government to manage public affairs and resources well in order to meet the needs of society. In terms of waste tyres as an aspect of solid waste, the Ministry of Environment and Sustainable Development is responsible for drafting policies and passing them down to the affiliated institutions to implement in their areas of jurisdiction. Poor governance has been identified as one of the challenges to efficient waste tyre services in Tunisia as this simply is not happening and policy is not being implemented at all. The findings of this research concerning poor governance (FMACM, EHS-1, and TOCI-1) support the opinions of Haouaoui and Loukil (2009) and Chaabane et al. (2019), who have all attributed that there is a poor state of waste management in Tunisia due to poor governance such as not implementing a sustainable system for waste tyre services.

The waste tyre sector faces several obstacles: mainly the lack of a collection, transport and recycling system. Although the collection and recycling of waste tyre was assigned to the private sector, this study reveals that five private firms were granted permission and authorization by the Ministry of Environment to collect and recycle waste tyre (GIZ and SWEEP-Net, 2014). However, only one of these five firms is still operating in the field of waste tyre recycling (CITET). The research findings revealed the bankruptcy of the other companies, which have closed their doors because there was no system in place to ensure financial sustainability and the continued flow of tyre waste (CITET). Lack of a system for waste tyre management has caused high costs of collection and transport of this waste. Consequently, most of this waste finds its way to be disposed of randomly instead of being recycled and utilizing its materials properly, for a variety of potential uses such as children's playground, running tracks, artificial sports pitches, fuel for cement kilns, carpet underlay, equestrian arenas and flooring.

In Tunisia, the recovery of waste does take place unless that waste has a market value. However, ANGED has failed to implement an appropriate system for sustainability concerning waste tyre management and to exploit this product as a source of valuable raw materials. However, the legislation and advancement in the integrated management of solid waste in Tunisia are notable within the context of the North Africa region. Notwithstanding this, the research results revealed that the lack of (appropriate) economic instruments to reduce tyre waste seems to limit the incentives for firms to recycle beyond what is beneficial to them. The other difficulties facing this sector include "that the imported rubber granules

are not subject to any customs tariffs, but rather enjoy an exemption from value-added tax while buying the same Tunisian product is subject to the payment of this tax" (TOCI-1 & 2).

5.1.1.2. Lack of Legislation and Policy Specifically to Tyre Waste in Tunisia

The findings revealed through the interviewees that Tunisia has been concerned with the environment since independence, but the pace of attention to legal issues and regulations has increased since 1988 with the creation of the ANPE. In 1991, Tunisia created for the first time a Ministry for the Environment (Mahjoub et al., 2020). The interviewee (MESD) stated, "One of the most important institutions affiliated to the Ministry of Environment that had a direct relation with waste management is the ANGED", which was established by Decree No. 2005-2317 in 2005. In this context, interview data revealed that in Tunisia the current legislation concerned with waste tyre management was the waste management Act (WMA) (1996-41), enacted in 1996. Accordingly, this legislation addresses the management of all types of wastes (WMA, 1996-41); without mentioning waste tyres management more specifically, the principles apply to the end-of-life tyres (ELTs), the objective of retreading and recycling activities, and this Act lacks details about the management of this type of waste (e.g. behaviour tyre stakeholders). Consequently, Tunisia has not defined an approach for end-of-life tyres. If a procedure for waste tyres management is not adopted, this may represent a serious threat to the natural environment and general health.

Another finding revealed that the lack of legislation mentioning what the obligations of tyre producers or distributors to organize the collection of used tyres and requirements of recovery or recycling of these wastes should be. The research revealed that in Tunisia, the tyre producers' activity involves only the selling and repairing of tyres, which limits the accomplishment of environmental sound objectives. Moreover, the study revealed that distributors are not legally obligated or required to educate the general public about the problem of waste tyre management or required to establish logistics for waste tyre collection. Moreover, there are no technical standards for tyre waste producers and owners. The outcomes pointed out that without setting up clear legislation and regulation, including economic instruments that are represented in EPR principles or the tax system, reuse, recycling or energy recovery and technology applications of ELTs is not possible for improving waste tyres management efficiency and decrease of dangers and threats to the natural environment. Both of the EPR and tax system work efficiently in many European countries respectively such as EPR in France, Italy and Spain while tax system in Denmark and Slovakia are effective for the management of waste tyres (Sienkiewicz et al., 2012). In

practice, however, stakeholders involved in waste tyres as an aspect of solid waste have entirely ignored the regulations. For example, the National Environmental (Waste Control, environmental protection and the fight against pollution) regulations, which provides the legal framework for the adoption of sustainable and environmentally friendly practices in waste management in order to minimise pollution and conservation of water and soil and quality of air. Although such laws exist, they are not enforced and as a result waste is not managed as expected. For example, under Environmental Law burning waste is unlawful and problematic, having a detrimental impact on public health and the environment. However, as highlighted by interviewees (Dealers-1, 7, 8, 10 and 13), (TOCI-2) and (EHS-1), the burning of the waste tyre is the way in which this waste is managed in order to retrieve raw materials. Despite the existence of laws to preserve the environment, however, there is a weakness in the enforcement of laws and regulations by the regulatory authorities. From interviews, it was found that there were no tyre collection centres created to accept and temporarily accumulate waste tyre disposed of by garages, private and public entities. Observations indicate that waste tyre owners, in turn, are physically responsible for the transportation of waste tyre to the disposal sites. For example, distributors are not under obligation to receive waste tyres when they sell new ones to their consumers. Accordingly, an implication to all these aspects is a clear operational gap in the national approach to deal with waste tyre regulation. During the discussion with the interviewees (ANGED) and (MESD), all of them acknowledged that Tunisia had adopted and ratified several important multilateral environmental agreements (MEAs), *"such as the Kyoto Protocol and the Basel Convention for environmental health protection, and had issued the Tunisia Waste Management Strategy. The strategy focuses on the application of three principles: the polluter-payer principle, producer-take-back principle, and citizens' right to information".* The 'polluter-payer principle' states that the cost of waste management shall be borne by the original waste producers (Dridi and Khraief, 2011).

The research revealed that Tunisia implemented the polluter-payer principle on many systems, such as ECOLEF that pertains to packaging waste and eco-oil pertaining to oil and lubricants, which is supported by eco-tax. However, there were no procedures concerning waste tyre or tyres being removed from vehicles before being scrapped so that they can be recycled.

The recommendations in the strategy do not specify the requirement or stipulate to dispose of waste tyres and how this can be achieved. Additionally, the research reveals that the

legislation did not prohibit the storage of tyres in landfills. Thus, the country faces critical challenges in managing waste tyres, which stimulates the need to develop innovative ways to recycle the increasing numbers of used tyres without storing them in landfills.

The absence of clear regulations and policies on waste tyre management not only makes tyre-recycling or energy recovery activities less attractive but also creates environmental problems. In light of this, an interviewee (CITET) explained, *"the companies that have obtained a licence to engage in recycling waste tyres have not been able to work in the absence of specific policy and regulations to regulate this sort of waste in terms of collection, transportation and recovery for tyre waste".*

Furthermore, as stated by the participant (CITET), *"There are different ways to manage waste streams and we are recommended to perform them, but the MESD and the ANGED have not yet developed a strategic plan for the waste tyre management".* While the participant (FMACM) maintained that… *"In the policy, it is written that waste ought to recycled or recovered, but there are no support activities for innovative work represent in the research and development projects to mainly develop new applications for material recovery from waste tyres".* Due to lack of knowledge and expertise in tyre waste management technologies, there is no consistent national approach for tyre regulation and implementation of functioning waste management policy measures aimed at creating community support. Furthermore, awareness about the management of waste tyres tended to be relatively lower in terms of customers being able to explain how to dispose of tyre waste in an environmentally acceptable manner. The researcher observed that it was emphasised by the participant (EHS-1) that the general public is not well sensitized and encouraged to participate in waste tyres management programmes. This may be due to the lack of appropriate waste management campaigns on waste tyres.

Therefore, it is essential for the Global South to adopt an effective system for tyre waste management. According to the EPR-based policies that have had positive effects in OECD countries, they are many suitable models for transplanting into Global South countries such as Tunisia. Moreover. Tunisia largely depends on brands of rubber tyres that are purchased from major international firms outside Tunisia that have experience of dealing with tyre waste, including major brand names (e.g. Michelin, GT Radial, Mitas, Lassa, Good Year, Petlas, Slideal, Continental, BKT, OZKA, Bridgestone, Henan, Hankook, Triangle, Nexen, Hero, Starmaxx, Cooper/Avon, Dunlop, Aeolus etc.). As most industry organizations in

Global North countries have ELT programmes, transferring expertise and know-how from these bodies to the developing world is key to encouraging better ELT management (WBCSD, 2008). Therefore, the implementation of a producer responsibility system in Tunisia can be effective, because the importers are fully familiar with the EPR system. Thus, the implementation of the EPR system leads to environmental sustainability according to the waste tyre hierarchy, regardless of the priorities order (as discussed in the literature review), as clarified by Van Ewijk & Stegemann (2016) who observe that the need is to 'move up' the hierarchy, rather than necessarily achieve the highest priority immediately.

5.1.1.3. Non-Implementation of Past Research Findings

Non-implementation of past research findings is another barrier to sustainable SWM in Tunisia. In spite of the fact that many studies have been conducted in Tunisia, which all advocate for improvements, evidence on the ground indicates little has been implemented; hence, improvement is lacking.

In this context, the participant who was the representative of the Environment and Heritage Society stated that many research studies had been conducted in the past into mitigating waste management crises (such as segregation of waste at source) but with nothing useful coming out of it, thus the participant sometimes felt that participating in research was a waste of time as it did not change anything; i.e. implementation of these research findings was almost zero. As another example, one of these cases related to non-implementation of past research findings in regulating informal trade, such as tyre smuggling, that the participant was sure could have contributed to the mitigation of tyre waste generation. As the participant pointed out, the smuggled tyres were poor quality tyres that had a short life span and therefore this exacerbated the problem of waste tyre generation and accumulation, which is difficult to manage properly.

Furthermore, the interviewees (EHS-1) and (ANGED-1, 2) mentioned that the parallel market [informal] for imported tyres had become a monopoly, with more than 70 per cent of the total local needs being met by this product as a result of its lower prices, which enticed the buyers to purchase this product in spite of its poor quality. This increased the generation of waste tyres in larger amounts than expected. Therefore, there are several studies dealing with the phenomenon of smuggling or informal trade of tyres, in terms of identifying the problem and finding a suitable solution. In this aspect, Tunisia took the path of liberalising its economy since the early 1990s and acceding to the General Agreement on Tariffs and

Trade (GATT 1) in 1994, becoming a founding member of the World Trade Organization (WTO) in 1995, it has thus adopted many laws and regulations that liberalised foreign trade. However, there are some exceptions to this policy, particularly those applicable to tyre imports (Ayadi, 2015).

In this regard, Ayadi (2015) stated in his study, conducted on behalf of the World Bank, that the tyre trade in Tunisia was characterised by strong market dominance by the informal sector in proportions far exceeding acceptable tolerances. The dominance was due to restrictions on imports imposed on ordinary importers. The main cause of the restrictions is explained in the price differences between neighbouring countries, due either to disparities in the levels of import taxation or subsidies for certain consumer products, in addition to bans and technical barriers to imports. The big difference in tax pressure, for example between Tunisia and Libya, stimulated the phenomenon of smuggling, because the value of import tax rate on the tyres in Libya represents 6% against 94% in Tunisia. Thus, importers in Tunisia in the formal sector bear various administrative fees, import duties and taxes, as well as taxes on consumption and income, and find it impossible to cope with the competition of those who benefit from smuggling. Therefore, the study proposes to allow the free importation of tyres meeting the technical standards in force by the importers holding the specifications, in order to fill the gap of prices between the formal and informal tyre trades. Thus, the state could introduce this reform, which would contribute to the reduction of smuggled poor quality tyres that increases waste tyre generation and accumulation. Furthermore, this reform would allow the maintaining of decent work opportunities, ensuring the sustainability of economic operators. Therefore, conducting and supporting research is extremely important. In this context, it is important to realize that one of the missions of the International Centre for Environmental Technologies of Tunis (CITET) is to support institutions through education and technical support programmes to improve their internal SWM systems, including waste tyre management. Therefore, the International Centre for Environmental Technologies of Tunis (CITET) should continue playing its role in supporting institutions through education and technical support programmes to improve their internal SWM system, including waste tyre management. CITET should also have sophisticated laboratories available enabling it to push for scientific research, especially concerning transferring its experience into tyre waste material recovery.

5.1.2. Waste Tyre Management Practices in Tunisia

5.1.2.1. Increasing Levels of Waste Tyres Due to Vehicle Fleet Increases

This research identified the lack of data about the level of waste tyre generated in Tunisia. Therefore, the researcher proposed a methodology in order to predict the range of waste tyre generated in the period of time between (2008-2012) by using the number of vehicles registered on the road. Table 4.2 shows the category and number of vehicles registered on the road in the period between 2008-2012 in Tunisia. Tunisia was home to some 1.6 million vehicles registered on the road. It may be observed from Table 4.2 that the vehicle numbers increased over these years, reaching their peak in 2012, with Tunisian roads busier than ever before. As is noticeable, passenger cars constituted the majority of vehicle types and they were the fastest-growing category.

According to the research findings, Table 4.4 and 4.5 indicate that the estimation of waste tyres arising in Tunisia in the period between (2008-2012), ranged from 1,220,381 to 1,581,061 units of a waste tyre, i.e. the average was 1,400,721 units or 9,805 tonnes, as summarised in Figure 4.12. It needs to be noted that the figures observed for waste tyres arising in this research study by passenger cars tend to be positively related to higher living standards, increase in car ownership and growth in traffic volume, whereby the private and public stakeholders widely used cars (associated with modernity). That is, populations tend to own more cars as they become more affluent, which ultimately leads to increased tyre use, leading to increased waste tyres arising, particularly in and around urban areas.

Therefore, knowing the number of waste tyre generated will effectively contribute to set proper management for this waste. As a result, it should be possible to assist organisers in deciding how to regulate the collection, transportation as well as processing and disposal or recycling and monitoring of these waste materials. These services could save a considerable amount of money and also prevent the environment from being harmed.

5.1.2.2. Lack of Formalized Waste Tyre Recycling or Energy Recovery Programmes

The research findings show that little is known about tyre recycling or energy recovery in the study area; observations, interviews with participants and government documents corroborated these findings and confirmed only one of the recycling companies out of five was still functional but struggling. This could be because the government is not actively supporting it.

Non-involvement of government in supporting waste tyre energy recovery or recycling and helping to set up formal systems, or supporting the informal sector, is a barrier to sustainable waste tyre management. The informal sector recycles in a crude manner, hence degrading the environment. Tyre waste recovery could be particularly helpful to communities managing their waste, thus reducing the waste that needs to be managed by the formal companies and its subsequent impact on the environment. The stakeholder interviewed (CITET) stated that attempts had been made to recycle waste tyres, but these failed due to the lack of support from the government. He emphasized the need for government to orient tyre producers by encouraging them to undertake material components recovery or energy recovery, preferably by recycling. According to the new philosophy, if waste cannot be prevented it must be considered a resource through which useful things can be recovered.

According to officials from different stakeholders, it is clear that unemployed people were burning tyre waste in order to retrieve raw materials and this phenomenon had spread throughout the country. It should also be noted that there were no licensed storage areas and energy recovery facilities. It is obvious that there is an urgent necessity for recovery and recycling facilities and licensed temporary storage areas in Tunisia in order to reduce the volume of waste tyres. Furthermore, there is an urgent need for an energy utilization option to be implemented. Worldwide it has been demonstrated to be economically viable because rubber tyres have a high heating value in comparison to typical coal (Tsai et al., 2017).

Gray-Donald (2000, p. 17) stated that "waste" should be regarded as an "untapped resource". The central options for achieving these goals are from strategies that evolve from a concept called the waste management hierarchy. The government should create a system that provides financial support towards the cost of plants, equipment and infrastructure for projects in Tunisia in order to reduce tyre waste stockpiles through increasing tyre recovery by turning waste into a new substance or product, and also seeking to create a sustainable market for the resulting products. In this regard, government should cooperate with universities and research centres to look for proposals to process waste tyres and a way to benefit from these new products in construction and manufacturing. This could be from the supply of raw materials created from tyre rubber processing or from the manufacturing of finished products incorporating recycled rubber.

5.1.2.3. Neglecting the Important Role of the Informal Sector

Waste collection and the recycling of the SWP, including tyre waste, was observed to be a hot topic in Tunisia. Many people were found to be involved in this activity and most worked

informally. This phenomenon could be observed in all of Tunisia's cities, both poor and rich districts. Informal waste collectors (named barbasha in Tunisia) are not visible, such as in the current ECOLEF system (related to packaging waste), likewise, in waste tyres (which is essentially lacking a system), informal waste collectors were overlooked even though they had an important role they play in preserving the ecosystem. In short, the interviewee (EHS-1) claimed that, the government does not recognise this segment of waste pickers (EHS-1). According to the NGO 'International Alert', two-thirds of all waste recycling in Tunisia is done by self-organized wastepickers; however, their profession remains unrecognized (International Alert, 2018). Informal collectors (wastepickers) depend mainly on the sale of secondary materials extracted from the waste stream to intermediate brokers, as was confirmed by a participant (FMACN). These collectors are able to obtain low prices that are a quarter (or less) of the physical value realised at the top of the value chain. Through a discussion with the representative of (ANGED), the reasons for the low levels of waste plastic collection was due to barriers mainly related to the price offered by private companies not a member of ECOLEF, which created a concurrence within the system. In some cases, problems were related to the inability of some ECOLEF points to accept the collected quantities due to non-congruence between the number of workers per point and the accepted quantities.

Under those circumstances, it is important to pay attention to this segment of society (the informal recycling sector), which is crucial in terms of pursuing a sustainable waste management agenda. Ezeah et al. (2013) express that the informal recycling sector can bring other benefits such as economic growth, and help to control garbage and conserve resources. The solution to this problem could be the integration of the informal recycling sector into the formal waste management system. To achieve informal recycling sector integration, it must be acknowledged that some of the crucial aspects to achieve this integration include social acceptance, political will, and a range of cooperative societies and partnerships within the private sector that have the necessary managerial and technical skills, as well as offering the informal sector legal protection measures (Ezeah et al., 2013). Therefore, inserting this labour force into the 'official' Tunisian economy could be of great help to this population in terms of social, health, economic, and environmental aspects.

5.1.2.4. Tyre Waste Practices by Producers as an Endpoint

Tyre waste generated by producers is treated in different manners around the world. In Tunisia, tyre producers themselves actually decide on their waste management strategies,

since finance, laws and regulation are not in place to regulate this kind of waste; therefore, the municipalities cannot enforce tyre producers to collect and transport their waste. Based on the research finding of the estimation of waste tyres in Tunisia, the results in Figure 4.12 indicate that the tyre producers generate an average 1,400,721 units/tyres as waste to be disposed of in landfill, whereas only a small proportion by the recycling companies are developing any kind of recycling initiatives. On the other hand, the option of energy recovery is not currently on the table. In the case of tyre waste generation, the ANGED and affiliated companies are responsible for the collection and transportation of this waste. This collection and transportation does not exist. In this case, waste pickers collect the waste tyres as recyclable materials from the landfills or garages for metal extraction to be sold or collected on behalf of a Recycler Company for a fee.

5.1.3. Resource Allocation

5.1.3.1. Lack of Sustainable Financing

Tunisia has experienced several economic difficulties, especially since the 2011 revolution (Fanak, 2015). In general, this has affected the services provided by the municipalities as they have lacked the financial means to perform SWM correctly. This is because the rate of recovering taxes is insufficient, whether from local citizens or waste producers such as packaging. The research revealed that tyre producers or tyre consumers are not subject to tax or levies as a contribution to the waste tyre collection services. Moreover, governments have not sought a set down effective financial mechanisms to support the move to environmental sustainability for waste tyres. However, Tunisia has established FODEP (called Eco-tax) such as that imposed on the packages (Eoc-lef). This fund was designed to help Tunisian companies gain better access to financing for environmental protection investments with the purpose of reducing their harmful pollutants and/or their use of resources. This was intended to make a contribution towards lowering environmental pollution and dangers to the health caused by Tunisian industrial, service and business enterprises. However, the fund did not targeted the segment of tyre producers. Furthermore, tyre producers or tyre consumers had not contributed towards the cost of the waste tyre management service as a result of no system being in place. According to what was reported by one of the participants (EHS-1), the stakeholders (decision-makers) may not see waste tyres as a priority area on their agenda, although this is contrary to the strategy adopted by Tunisia in terms of integrated SWM.

The literature review revealed that the economic instruments such as taxes, charges, or tradable permits etc. are a key part of the overall policy mix for waste management. Economic instruments have played an important role in the context of integrated waste management within Global North countries. Economic instruments have received special attention as a significant tool for the promotion and implementation of environmental legislation, while contributing at the same time to sustainable development (Hannequart, 2002). Therefore, economic instruments can be used to deter environmentally damaging activities, improve social equity, raise revenue or recover public-sector costs (Buckley, 1991). Moreover, the research revealed that economic instruments can be an effective policy instrument in the prevention, minimisation and sound management of waste tyres. Fees and charges are economic instruments that can be used to recover the costs of waste management and support the principle of user pay, helping to ensure the financial sustainability of waste management services. Von Moltke (2004) expressed that the use of economic incentives has great advantages in terms of achieving the desired effect at the lowest possible cost; in particular, they are vital to those countries with limited enforcement budgets that rely only on the rules of command-and-control, as is the case in many countries in the Global South. Economic instruments such as extended producer responsibilities (EPR) support the principle of 'polluter pays' by internalising environmental and human health costs.

EPR has proved to be one of the most efficient multi-target policy instruments to manage waste in an environmentally safe way for end of life products. In order to achieve an effective and successful EPR, a country needs to have solid regulation for the implementation of the EPR system and keep control of the informal sectors, particularly in Global South countries (Gupt and Sahay, 2015). Gupt and Sahay (2015) conducted a comparative analysis of the common activities of EPR in the upstream and downstream stages of 27 selected cases of EPR in practice in both Global North countries and Global South countries, which indicated that the EPR is successful when the role of producers is restricted to carrying out financial responsibility (flow of finance), while the physical responsibility of collection and recycling is outsourced to a separate organisation such as a producer responsibility organisation (PRO), i.e. restricted to collection and recycling that will have a positive impact on the system of the EPR. In this regard, upstream management of the EPR system seems to be most important, because the flow of finance is essential for the proper functioning of any EPR system.

5.1.3.2. Lack of Assessment in Waste Tyre Management Planning

To perform effective planning of tyre waste management as an aspect of SWM in the business sector of tyres, many parameters should be considered, such as the stakeholders, the tyre dealers, and the number of vehicle owners and vehicles agencies and dealers. In this context, the vehicle fleet increases in Tunisia are shown in Table 4.2. In fact, there is no concrete data on this issue, (e.g. a number of new tyres imported or tyres fitted to vehicles, or numbers of scrap vehicles taken off the road and the waste tyres resulting, nor quantities of waste tyres in official or unofficial dumpsites etc.) with which to conduct effective waste tyre management planning. This is what the representatives of (CITET) and (ANGED-1) emphasised: that the government lacks the necessary statistical data relating to waste tyres generated, whether that is stockpiled in official or unofficial dumps, stored or even abandoned. This is in consonance with similar literature showing that systematic records of waste tyre data are virtually non-existent in Tunisia (GIZ and SWEEP-Net, 2014). This is an obstacle to knowing the fate of waste tyres and planning the introduction of a legislated recycling process of waste tyres. Generally, it is common that there is a lack of data on used tyres production and collection, as well as small activities of uncontrolled waste recovery, with cases of illegal dumping, in Global South countries (Torretta et al., 2015).

Essentially, the results indicated that the non-involvement of all market players (distributors, garages, waste-managers, etc.), replacement of tyres or imports, penetration levels of automobiles and the life duration of tyres, may lead to higher generation of waste tyres. This can impair the design of a waste tyre management system to obtain the value of recyclable materials (e.g. rubber) that can be recovered from waste tyres. Furthermore, general data on the lifespan of tyres (e.g. when a tyre is expected to reach its end-of-life in use) were not readily available, resulting in a lack of information concerning the peak in new tyre sales. It is clear that the dynamics of this waste tyre management practice are lacking in Tunisia, and it is not easy to project the economic costs associated with waste tyres processing in the future without knowing the rate of waste tyre production. This situation is due to a conjugation of factors, such as the fact tyre importers and producers do not provide data on tyre sales. Similarly, Statistics Tunisia has no available data on the production of waste tyres and the annual trade of tyres. This is partly because some tyres are usually removed and fitted onto viable vehicles once the older vehicles have reached the end of their working life and cannot be reused again.

Data should therefore be collected and organized by local authorities, Ministry of Local Affairs and Environment (MLAE), and ANGED in collaboration with the Technical Agency of Terrestrial Transport (ATTT) affiliated to the Ministry of Transportation, local NGOs, and universities. Such data would be an excellent asset in supporting the decision-making process and waste tyre management planning in these areas. Without proper data on tyre waste flow, with regards to waste tyres stockpiled at landfills, it may be hard to design sound strategies and plan for waste tyres management. UNECE (2016) emphasised that the statistics on waste are crucial to inform different international policy frameworks and for regional, national and sub-national waste management policies.

5.1.3.3. Lack of Monofill

The safe disposal of waste tyres as an aspect of solid waste through controlled methods is a fundamental element of an SWM system. The research investigations established that no monofill exists in Tunisia for waste tyre disposal as the last option in the waste hierarchy. Monofill can be considered as a temporary short term solution that is more desirable when compared with landfill, because it contains scrap tyres only that can be used for energy recovery or recycling in the future as an alternative to virgin raw materials. Thus, this solution can offer a positive environmental impact in terms of using waste tyre as a significant resource, mostly derived from the accompanying reduction in virgin resource exploitation (WBCSD, 2008). But in return, the monofill should be managed by strict regimes to avoid environmental risks that may occur. Although they continue to use landfill and waste piles, most but not all Global North countries now view landfills (waste piles and dumps) as the least desirable option for ELTs. Tyres are banned from landfills in many countries, such as those in the EU. Eleven states in the US place a total ban; a further 31 states have restrictions requiring shredding or monofilling (WBCSD, 2008). These countries imposed banning due to the some of the environmental and public health problems unmanaged disposal causes, such as discarded stockpiles promoting mosquito development, which are vectors of diseases (Ferrão et al., 2008; Leff et al., 2007); fire hazard (Ferrão et al., 2008); tyres fires being difficult to extinguish (Lisi et al., 2004) and can contaminate surface and sub-surface water, air and soils (Leff et al., 2007; Shalaby and Khan, 2005); leaching problems occur with metals and some substances added to the rubber (WBCSD, 2008); visual impact on the landscape (Ferrão et al., 2008).

The stakeholders interviewed emphasized that lack of a monofill is a major barrier to tyre waste management in Tunisia as this encourages waste producers to continue to dump waste openly in the government-designated landfill or at open dumpsites. In this regard, the research has revealed that the massive open dumps located at Great Tunis were not fenced off and had settlements in close proximity, which is poor governance. Although, the government set a range of measures and programmes to close and rehabilitate uncontrolled landfills in order to reach sustainability and the integration of waste management, this has never come to fruition. This is due to many reasons; for example, legislation in Tunisia does not distinguish between municipal and (non-hazardous) industrial solid wastes, which leads to both types of waste ending up in the same landfill. In addition, there is a lack of citizen and NGO participation in waste management policies and strategies, which is one of the reasons for the closure of these landfills.

5.1.4. Attitude of the Public

5.1.4.1. Non-Engagement of Tyre Producers, Communities and NGOs on Waste Management Decisions

Interviews with a stakeholders (ENGAD) and (Dealer-13) highlighted that the government had not been engaging with tyre producers and NGOs in discussions regarding waste tyre management. This can be confirmed through statements from stakeholders, who stated:

The waste producers and NGOs are not involved in waste management decisions because government laws or policies had not made this possible, especially in the era of the former regime before the revolution (MESD). With the downfall of the authoritarian regime, SWM entered a phase of instability, triggering a number of protest mobilisations in response. As a result, the waste producers and communities feel neglected; therefore, they manage waste in the most convenient way for them, which has increased the number of open waste dumps. This situation is common throughout Tunisia, as observed by the researcher in waste tyres (OBS). The situation became all too familiar to both citizens and tourists visiting the country on holiday.

Loschi (2019) stated that the environmental protest mobilisations after the revolution of 2011 become familiar. As an example of what happened, Borj Chekir landfill was closed by protesters, due to residents' objection to the existence of landfills such as Borj Chekir in a residential area that caused bad odours and diseases to local people. In addition, demonstrations spread from Djerba, a tourism-centred island in southern Tunisia. The

situation of the environment protest created a network of activities to address general environmental challenges and waste management problems in Tunisia. Therefore, the participant (EHS-1) suggested that the decision-makers must have considerable attention to the need for community participation and involvement in wider processes of public decision making, in order to achieve waste management sustainability.

Based on the concept of evolving sustainable waste management, the main strategy in this regard is integrating the four dimensions of management options, stakeholders, related systems and driving forces (as stated in Para 2.2.1.3) in order to achieve sustainable objectives such as waste tyres. Goodey (1971) justified the approach of this strategy by arguing that according to the studies in environmental psychology, ego involvement through public participation leads to reduced friction, less argumentative debate, and less resistance, rejection and confrontation. It has been widely recognized that waste management systems that ignore social elements are doomed to failure, thus the public participation in planning and implementation stages is equally as important as the technical and economic aspects of waste management (Carabias et al., 1999; Dijkema et al., 2000; Henry et al., 2006).

In this context, the interviewee (CITET) highlighted that *"it is the time to focus on the awareness among citizens through the involvement of citizens and civil society organisations in waste management issues, and the establishment of transparency in order to promote environmental sustainability"*, and continued by saying that *"I would like to orient the political forces with different ideologies so that they must bear in mind the environmental agenda, which should not be included in the political conflicts, but should be under political spotlight stage".* In this regard, Carmin and Fagan (2010) revealed how institutions of civil society have become less effective in the field of environment, as the preservation of environmental issues has been largely in the political limelight. A better example of an awareness campaign, "Let's do it," began in 2008 in Estonia, Lithuania, and later spread to other countries, and could be seen as an interesting case for a successful environmental campaign in the field of waste management and a useful campaign to raise awareness and increase public participation and reduce pollution. This campaign is an inspiring example for the countries of the Mediterranean region in order to promote the environmental work program (Sömersalu, 2014).

5.1.4.2. Lack of Public Education and Awareness of Waste Tyre

The way people think and feel about waste stream determines their waste behaviour (Teo & Loosemore, 2001; Wang & Yuan, 2011). In Global South countries, including Tunisia, waste

is viewed as dirty and so no one wants to be associated with it (Oyeniyi, 2011). The lack of concern from waste producers and government officials who lack the will power to improve the management of the waste stream is a challenge, supporting the findings of Chaabane et al. (2019). In general, the attitude and perception of people towards environmental issues affect how they obey environmental policies and engage with environmental programmes. The lack of awareness and concern on environmental issues influences waste behaviour. The stakeholders interviewed highlighted that the attitude of waste producers towards waste was a challenge to effective waste management in Tunisia. Poor attitude towards tyre waste was observed in the way dealers handled waste tyres, discarding it carelessly in public spaces without regards to public health and the environment. Discarding of waste tyres throughout the community instead of at a designated tyre waste monofill makes it difficult to collect waste tyre, resulting in unsanitary environments.

For example, the results of the research, on one hand, revealed that the general public was misusing the standards of tyres in terms of purchasing smuggled tyres instead of suitable quality tyres. On the other hand, they disposal of waste tyres in open environments led to the creation of random dumpsites. It was common to see tyre waste producers leaving their waste tyres on the streets. There were tyre waste dumps in the open environment due to the lack of consumer awareness to build appropriate attitudes towards tyre utilization. The inability to educate members of society on waste tyre issues could be the principal reason behind the indiscriminate disposal of such waste in Tunisia, in addition to the lack of relevant education and communication programmes and the absence of adequate infrastructure. All this was in spite of Tunisia enacting the National Program for SWM (PRONADGES) in the 1990s and establishing the ANGED in 2005 (Mahjoub et al., 2020). However, the existence of these legislations did not guarantee a waste-clean country, especially in the post-revolution period. After the departure of Ben Ali, everyone remembers that on January 15, the streets were flooded with filth includes waste tyres (EHS-1, 2). Therefore, waste minimization from the source requires changes in the behaviour of people, either collectively or individually such as companies, vehicle owners and tyre producer by dissemination information, whether educational or training on waste reduction policies and programmes by simple claims (e.g. pamphlets, handbills, posters, brochures, radio and television ads) - in order to create an understanding of what needs to be done and why, and how it can be done (Vining & Ebreo, 1989; Simmons & Widmar, 1990; Katzev & Mishima, 1992; Margai, 1997). Whatever policy measures are utilized, they will require support with coordinated information

campaigns, both to advise people what they are required to do and to persuade them to do so (Wilson,1996).

5.2. Management Options That Most Sustainable For Final Destination of End-Of-Life Tyres from A LCA Perspective

5.2.1. The Geographical Distribution of Selected LCA Studies

A comparison of the papers presented in Table 5.1 shows that the studies are concentrated in China, the United States and Europe, this reflecting the existence in these countries of active LCA communities and public interest in LCA results as a means of contributing to the decision-making process in selecting the best technological alternative from an environmental perspective.

Table 5.1 Studies That Are Produced the Most LCAS of Waste Tyre Management in Three Different Continents

Countries located in the continent of Asia			**Countries located in the continent of America**			**Countries located in the continent of Europe**		
Authors	**Number of Studies**	**Location**	**Authors**	**Number of Studies**	**Location**	**Authors**	**Number of Studies**	**Location**
Li et al. (2010)	3	China	Fiksel et al. (2011)	3	USA	Ferrão et al. (2008)	2	EUR (Portugal and France)
Li et al. (2014)			Feraldi et al. (2013)			Clauzade et al., (2010)		
Sun et al. (2016)			Ortíz-Rodríguez et al. (2017)					

It is clear that the LCA studies on tyre waste management have become of global interest in many countries and regions, such as America, Europe, and Asia. The first concept of life cycle analysis of products was initiated in America in 1969 but was called Environmental Profile Analysis (REPA). The concept is attributed to Harry Teasley, then with The Coca-

Cola Company. The purpose of conducting LCA by Coca-Cola Company was to compare different beverage containers to determine which produced the fewest effects on natural resources and the environment. Meanwhile, in Europe they began to pay attention to LCA in the 1970s (Hunt et al., 1996). In China, LCA research was initiated when the first article was published in the International Journal of LCA on life cycle assessment (LCA) in 2001 (Nie, 2013). It is worth noting that no study of LCA for waste tyres has been conducted in Africa, including Tunisia, according to the systematic review that is conducted in this study. This may be attributed to the different economic development stages, environmental awareness, and LCA data availability, or may be caused by the generally poor penetration of LCA in these regions, or for other reasons that studies are published in local languages, which prevented their inclusion in the review. The Global South countries typically include waste management structures and practices, which can cause various environmental problems, such as health impacts from the waste handling/ collection or informal recycling/recovering (e.g. Bleck and Wettberg, 2012). Credible data, which could be used for performing harmonious LCA studies, are probably not readily available in these regions yet (Karak et al., 2012).

5.2.2. LCIA Method Preference

The aim of the LCIA is to determine and assess the magnitude and significance of the potential environmental impacts of the system studied. In this stage, the functional units allow the relevant data to be compared. Inventory data are divided into midpoint (Hauschild et al., 2013), and endpoint (human health, ecosystem quality, and resource consumption) and converted into units via weighting factors for comparison (Kägi et al., 2016).

Since the functional units have yet to be standardized, numerous names have been suggested, such as Ecopoint unit. In this case, the values for each impact category are summed to produce a single value known as the Ecopoint, which corresponds to the environmental load of 1000 Europeans over a one-year period (Chiu et al., 2008; Kägi et al., 2016). In the interpretation phase, the results of the previous stages are compared with the goal and scope in order to draw conclusions and provide recommendations.

In selected papers, the LCIA methods identified in the studies were classified into damage-oriented (EI 99; ReCiPe, 2008) and problem-oriented (CML; EDIP 2003; TRACI) methods. The damage-oriented method models the cause-effect chain to endpoint level, or in other words, the impact leading to damage to the environmental areas of protection, which are

represented in Ecosystems, human health and resources, while the problem-oriented method models to the midpoint level. Another explanation can be given to differentiate between the two methods (midpoint and endpoint). Firstly, in the midpoint method, the cause-and-effect chain begins with a specific process or activity leading to emissions and thus, the initial changes in the environment appear. These initial changes often occur early in the cause-effect chain as chemical and physical changes. For instance, if the initial effects of climate change are studied, the changes in concentrations of gases in the atmosphere or changes in infrared radiation will be observed. At this stage, the results of LCI represent contributions to various environmental problems such as global warming or depletion of the ozone layer in the atmosphere. This is called the midpoint method. The midpoint method is also known as the problem-oriented approach. Later, in the cause-effect chain, biological changes often occur, which are represented by damage to ecosystems, human health, and resources. For instance, one of the damages to human health caused by stratospheric ozone depletion would be an increase in skin cancer. This is called the endpoint method. Therefore, the endpoint method is known as the damage-oriented approach (Gernuks et al., 2007). According to above mentioned, there are differences observed between LCIA methodologies according to the environmental modelling approach (midpoint and endpoint).

In addition, there are other differences that can also be observed, according to the European Commission (2010), such as:

• The number of impact categories covered by each methodology (midpoint and endpoint categories).

• The number of materials covered by each methodology.

•The corresponding criteria and models required for the steps of characterisation, normalisation, and weighting, which thus affect the regional validity of the methodology; thus, a question might arise to determine whether the methodology was developed based on the environmental background (environmental profile) of a given continent or country (spatial differentiation). Another question that may arise is the timeliness of the data used, which questions whether the data used in modelling are too old to fit current changes in the environment.

In accordance with the aforementioned, figures 5.2, 5.3, 5.4 & 5.5 reflect the framework of LCA methods, which illustrates their differentiation. These methods are different in many aspects in terms of the assessment level in the cause-effect chain, spatial scale, impact category, time scope, substances covered, and indicators. In such a situation, it would be

difficult to challenge the preference of an LCIA method when carrying out an LCA study on waste tyre management. Therefore, there is no consensus concerning the best impact method for tyre recovery studies, although regional preferences are observed. For instance, European paper studies showed a preference for Ecopoint (Ferrão et al., 2008), while American papers used only the TRACI method (Fiksel et al., 2011; Feraldi et al., 2013), Chinese authors applied two methods, represented by Eco-indicator 99 and CML, and a Colombian paper uses the CML (Li et al., 2010; Li et al., 2014; Sun et al., 2016; Ortíz-Rodríguez et al., 2017). It is important to underscore that more LCA studies are needed in order to better understand the impacts of alternative options to traditional tyre management, especially when tyres are submitted to new industrial processes, such as recycling (Stindt & Sahamie, 2014; Karaağaç et al., 2017).

Figure 5.2 Framework of CML Method for the Baseline Impact Categories (Guinée et al., 2002, p.147).

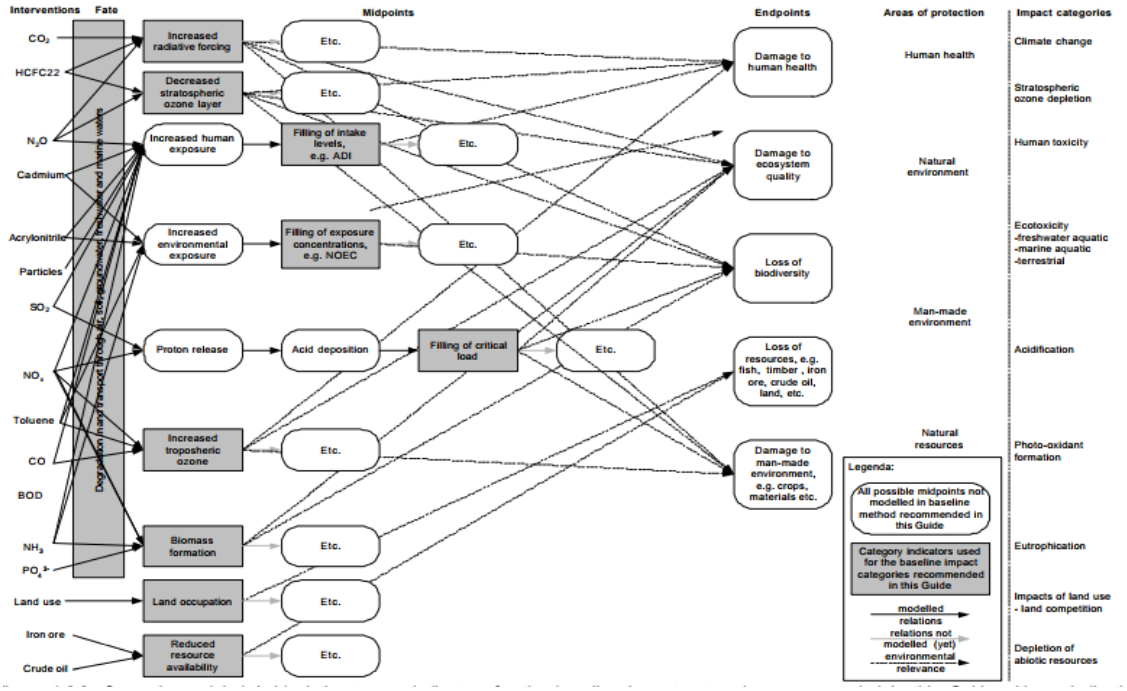


Figure 5.3 Framework of ReCiPe 2008 Method (Goedkoop et al. 2009, p.3)

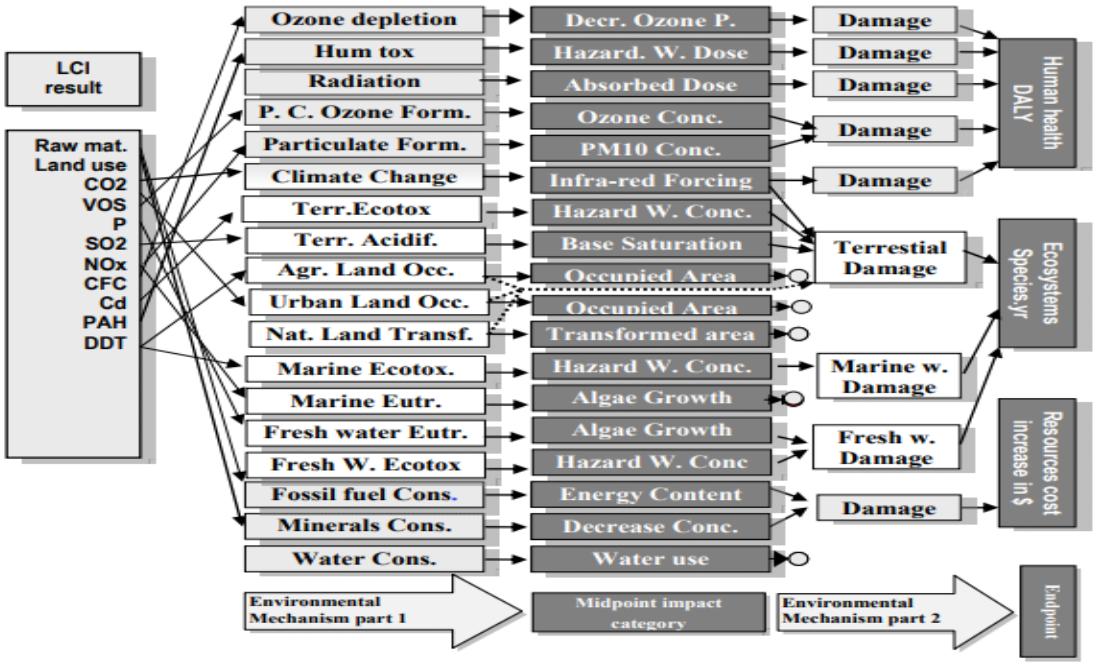


Figure 5.4 Framework of Ecoindicator 99 Method (Goedkoop and Spriensma, 2001, p.10)

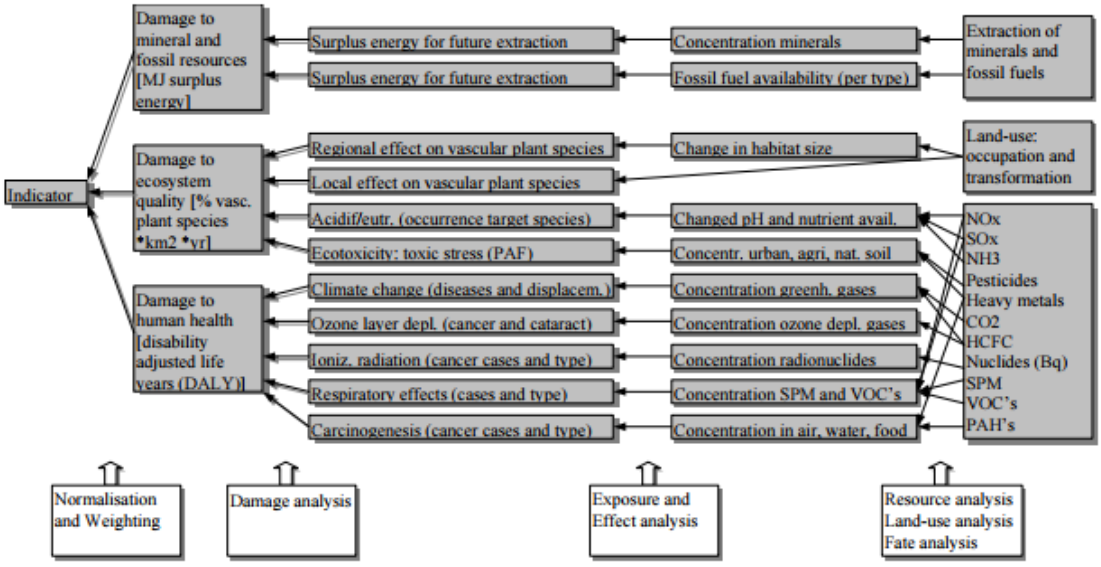
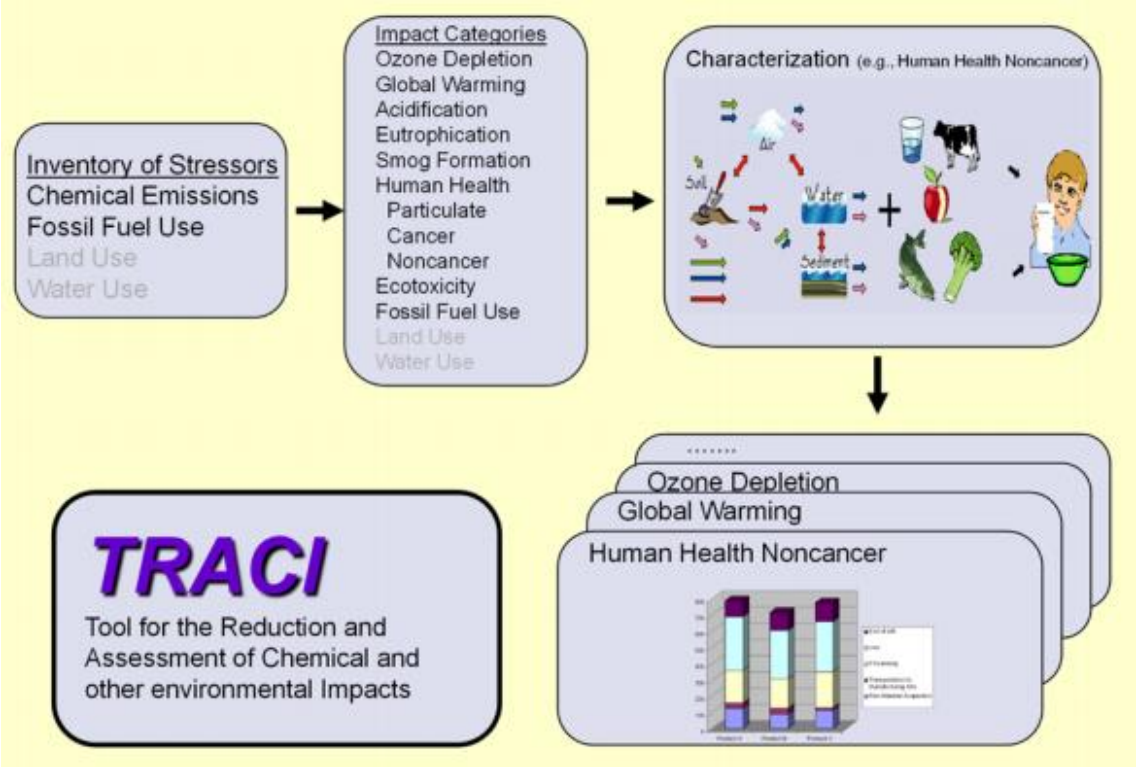


Figure 5.5 Framework of TRACI Method (Bare et al., 2012, p.8)



In view of the above, a number of impact assessment methodologies are available to the LCA. The life cycle impact assessment methods as (CML, ReCiPe 2008, Ecoindicator 99 and TRACI) differs in their performance through application to the same life cycle inventory from a study. For example, the impact assessment methods are that the CML2001 method has a problem-oriented approach to impact assessment as opposed to the Eco-indicator 99 method which has a damage-oriented approach. This means that while the former model the impacts at a midpoint somewhere in the environmental mechanism between emissions and damages, the latter aims at modelling damage to the protection areas: human health, natural and manmade environment and natural resources. Therefore, it difficult to perform a meaningful comparison between methods due to the difference in approach to impact assessment.

According to above mentioned, in the case of Tunisia decision-makers desire to conduct LCA for the waste tyres, it is important to specify LCA software that appropriates in terms of database and modelling approaches to meet the specific goal required to satisfactorily answer the question(s) posed for study. As there are different forms of LCA software that integrate a large number of universal databases and environmental impact assessment models (Piotrowska et al., 2019). Specifying data source (life cycle inventory data [LCI]) in

conducting LCA is the most important thing to provide sufficient accuracy and quality to meet the study goal. This because LCIs plays a very conclusive role because the reliability of the final LCA results is based on the quality of the collected data (Curran, 2012).

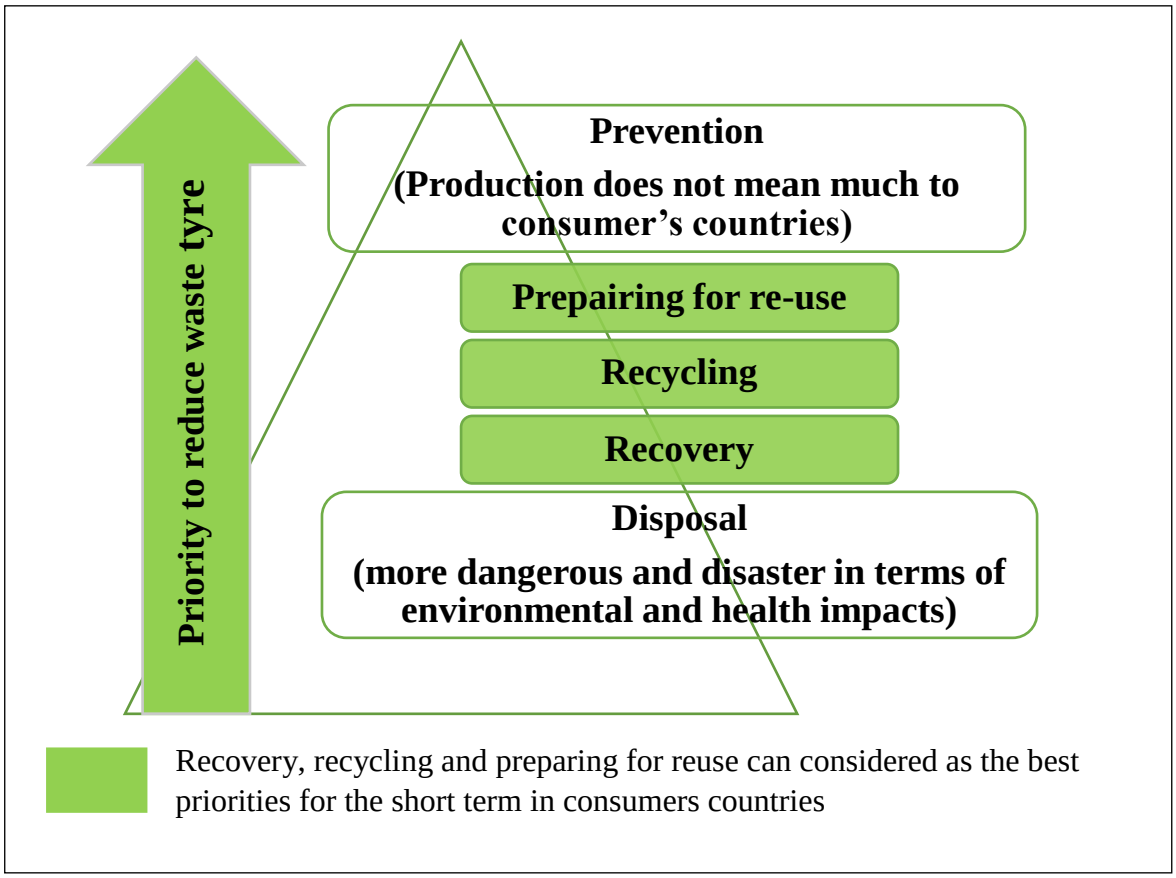
5.2.3. Final Destination of End-Of-Life Tyres that are Most Sustainable from an LCA Perspective

End-of-life tyre disposal was shown to be of great interest in Asia, America and Europe, as a means of contributing to the decision-making process in selecting the best technological alternative from an environmental perspective. Selected studies demonstrated that the best environmental performance, in general, was mechanical recycling for utilizing in artificial turf. Meanwhile, the worst environmental performance was observed in co-processed and retreaded tyres. There is no unanimity regarding the best tyre recovery method, in spite of regional preferences being observed. However, Clauzade et al. (2010) emphasised that all applications for car tyres recycling/recovery provide environmental benefits.

Despite the fact observed that the disposal of used tyres in Tunisia is uncoordinated and haphazard. Therefore, Tunisia must, in the short term at least, take steps to reduce waste tyre, as one of the main strategic horizons for waste management according to the principles of a hierarchy that provides a set of options regardless of the priority order. As emphasised by Van Ewijk & Stegemann (2016) that the hierarchy is that one needs to “move up” the hierarchy, rather than necessarily achieve the highest priority. Despite prevention (that comes on the top of waste hierarchy in priority order) through reduction at the source of production does not mean much to consumer’s countries such as Tunisia. While the landfill becoming more dangerous and disaster in terms of environmental and health impacts such as disposing of the waste tyre at the landfill for either South or North global countries (Van Beukering and Janssen, 2001; Ferrão, 2008). Moreover, as mentioned in the literature review about the new philosophy that states if waste cannot be prevented, it must be considered a resource through which useful things can be recovered. Waste recovery should be seen not only from an economic perspective (as in the past) but also as environmental protection for present and future generations. This concept is known as ‘Resource recognition’ (Furedy 1992). Allenby & Richards (1994, p.69) emphasised that the post-consumption waste, industrial scrap, and unwanted by-products from manufacturing processes should not be considered waste. Instead, they are raw materials that are often significantly underused. In the same context, Gray-Donald (2000, p. 17) stated that "waste" should be regarded as an "untapped resource". The central options for achieving these goals are from strategies that

evolve from a concept called the waste management hierarchy. Therefore, can be considered tyre waste disposal from bottom to top as a priority in the waste hierarchy for those consumer's countries such as Tunisia as illustrated in the flow diagram (figure 5.6).

Figure 5.6 Illustrating the Flow Diagram Hierarchy of Tyre Waste Disposal Priority for Those Consumer's Countries Such as Tunisia



Source: The author

In the context of the systematic review for selected LCA studies of waste tyres that analysed the environmental burden of a wide range of applications, this generally indicated that the recycling/recovery tyre applications provide environmental benefits regardless of the preferences. Valente and Sibai (2019) emphasised that recycling tyres leads to significant economic and environmental benefits, based on the recent report prepared by John Dunham and Associates; indicating that the tyre recycling industry generates US$1.6 billion a year, and creates jobs. While from the environmental aspect, indicating the major international waste recycling companies are working to increase the rate of tyre recycling above 90%. Therefore, this goal will reduce some of the negative effect of tyre waste on the environment. Thus, consumer countries such as Tunisia need to move up to the waste hierarchy from the

bottom (disposal to landfill) to the recycling and recovery level in order to achieve sustainability. Of course, reusing unequivocally provides more benefit to the environment. To ensure it moves up the waste hierarchy, there are various policy measures/instruments Tunisia needs to be present as they are important (as mentioned in para. 2.3.2) in supporting implementation of waste hierarchy to achieve more sustainable waste management. Nevertheless, in the long term Tunisia can carry out internal LCA studies for waste tyres when it needs to make a decision that significantly influences the treatment improvement or development process as the treatment technologies are in continuous development.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATION

6.0 Conclusions, Limitations and Anticipation, Recommendation and Future Work

6.1. Conclusions

The present study provided a comprehensive investigation of stakeholders and many key aspects that affected the practice of waste tyres management in Tunisia. The research noted the problem largely results from the lack of government commitment to address the issue of tyre waste management. Tunisia faces an issues of the flow of informal importation of poor quality tyres by smugglers on borders. Imported informal tyres (smuggled tyres) are offered at low prices and without-quality-check-controls. Poor quality tyres increase the waste tyre generation and accumulation. It could be inferred that the flow of smuggled tyres cause's problems with tyre waste control in Tunisia, contributing to the problem of waste tyre management.

The absence of adequate legislation created many illegal waste tyre dumping sites in different areas of Tunisia, where unemployed people use them for various purposes. The current state of unregulated disposal poses a serious threat to human health and the environment. Evidently, there is an operational gap in the national approach to dealing with the regulation of tyre waste. It is therefore difficult to track and prosecute the perpetrators of any illegal dumping of tyre waste. Thus, it can be said that the existing policies, laws and regulation cannot address the issues of waste tyres in terms of storage, collection, transportation, and exploitation of the value and final disposal of waste tyres. Although used tyres are ultimately considered as a waste, the results also revealed that the tyre producers and community in general are unaware of the role of the government with respect to waste tyre management. The responsible authorities in the country have failed to promote partnership with the tyre waste-producers or to involve them in the various aspects of waste management including needs assessment, financing, waste collection and final disposal.

At the level of institutional frameworks in Tunisia, the Tunisian government has different institutions involved in waste management. The ANGED is responsible for transportation and disposal of waste from transfer centres to landfills, while the municipalities are responsible for waste collection from source and transporting it to the transfer centres. The

central government through the Ministry of the Environment and Sustainable Development formulates waste management policies. However, the government has not taken full responsibility for tyre waste management as a matter of environmental importance and has not provided an approach to establish a model applicable to tyre waste management, with a view to preventing waste, and to developing collection, transportation and participation activities in their environmental actions with stakeholders.

In summary, it should be noted that most of the major issues reflecting the current situation in the country, particularly the deficiencies in the management of tyre waste at the national level in Tunisia, are as follows:

- Exacerbation phenomenon of smuggling or informal trade of tyres in Tunisia.
- Waste tyre generation increases steadily and inevitably without treatment.
- The government has no involvement in regulating waste tyre management.
- Lack of commitment from participants and all stakeholders in waste tyre management.
- Lack of innovative engineering applications of waste tyres and recovery process.
- The absence of a systemic and consistent policy and legislation specifically mentioning guidelines for waste tyre management.
- The dearth of public awareness and capacity building programmes.
- Lack of mandatory information and records available.

This study showed that an effective system is based on the technical, environmental, economic, legal and institutional aspects that should be present to ensure the overall efficiency of the system. It is clear that new and innovative technologies and processes can easily take away a significant portion of scrap tyres from the environment and convert them into valuable materials, thus reducing the environmental impact associated with their dumping at landfills.

6.2. Limitations and Anticipation

The anticipated issues were in relation to the unavailability of data from Tunisia, such as basic statistics of the waste tyre quantity generated annually. Since the management of waste in Tunisia has not yet been institutionalised, as in some of the EU member countries, bureaucratic barriers were anticipated in this context. It was also anticipated that difficulties would arise in making appointments and arrangement for the interviews with the right authoritative person or officer. However, the researcher made every effort, with the

assistance of NGOs to identify the correct person who had the responsibility on matters related to the management of waste.

The problem of timing for interviews were of great concern during the survey in Tunisia. Each interview took about an hour and a half on average, with the exception of the time that the researcher used to browse the departmental documents and as well as rapid reviews with NGO collaborator to confirm that notes of French words were taken.

It is the responsibility of the researcher to ensure enough funding before committing himself to any task. The funding and resources needed for travelling and lodging during the data collection in Tunisia were on a 'tight budget' basis and as a result, comprehensive and expansive consultation with the numerous stakeholders was not always possible. As such, the researcher limited the survey to some of the main government departments and one of the municipalities located in the capital, Tunis.

6.3. Recommendations

Tyre waste management in Tunisia is a major concern due to insufficient and weak performance of legislation, lack of cooperation among stakeholders and public participation in safe disposal methods for tyre waste. Therefore, this suggests the need for concerted effort to implement appropriate and viable measures for an effective tyre waste management system in Tunisia and similar countries. In this regard, the following recommendations are made to address this problem of waste tyres management for safe disposal.

6.3.1. Stricter Commercial Measures with the Implementation of Past Research Findings

Stricter control with enforcing the laws in order to eliminate the informal importation of smuggled tyres is also called for. Not only do informal imported tyres add to the volumes that will later have to be disposed of, but informal imported tyres (smuggled tyres) add to the problem of tyre safety. Tunisia has a legal option based on laws and regulations that liberalized free trade according to the General Agreement on Tariffs and Trade (GATT) which allows it to reduce or eliminate the informal smuggled tyres. Therefore, Tunisia should adopt the proposed study conducted by Ayadi (2015) on behalf of the World Bank to allow the free importation (i.e. free of various administrative fees, import duties and taxes) of tyres meeting the technical standards enforced by the importers and having the specifications to fill the gap in price between the formal and informal tyre trade. Thus, the

state could introduce this reform, which would contribute to the reduction of smuggled poor quality tyres that increases the waste tyre generation and accumulation.

6.3.2. Effective Legislation, Regulation and Waste Management Policy

An integrated national pollution and waste management policy, which would ensure that the fragmentation in dealing with waste and pollution are eliminated, and would also determine the success of tyre waste management. Stakeholders' participation and public participation in the management of waste tyres is essential to ensure the recovery of waste tyres and eventual planned disposal. The incentive to collect and appropriately dispose of tyres must be attractive to maintain consistent engagement from the stakeholders and the general public. Tunisia may have to legislate for among others, the collection, transfer and disposal of waste tyres.

6.3.2.1. Legislation and Regulatory Measures

In this regard, a national policy for both the form of regulations and their strict enforcement is recommended for tyre waste management. Therefore, the amendments to current legislation and regulation should include the following measures:

- Include the legal basis of banning the disposal of tyres at landfills, prohibit stockpiling of waste tyres at landfills and encouraging shredding and recovery of tyres in the current legal framework.

- Include the legal basis for the collection, transportation and treatment system for waste tyres in the current legal framework.

- Provisions to determine the authority/agency/organisation that is responsible for the new collection, transportation and treatment system.

- Provisions for the description of the new system for collection, transportation and treatment of waste tyres. This description should include: define/categorise used and waste tyres, regulations specifying how the waste tyres should be collected, transported and stored, specifying licensed collectors and their jurisdiction, register recyclers and detail their activities.

- Provisions to specify a regulation relating to the materials energy recovery process as the burning of waste in processes such as cement kilns, in which emissions issued by the process of burning tyres do not exceed the specific local standards and are in accordance with the international conventions concluded with Tunisia.

- Provisions to specify the penalties for waste tyre generators, handlers, and collectors who violate the law.
- Provisions to specify the collection of fees.
- Provisions requiring all sectors involved in tyre waste generation and disposal chain to keep proper and accurate records of the number of tyres they handle.
- Establish an agreement of stakeholder understanding across the supply chain (tyre manufacturers, tyre importers, waste tyre generators, collectors, recyclers, vehicle manufacturers, agencies for automotive importers etc.) to ensure discarded tyres are collected and recycled or recovered and to improve product sustainability.

6.3.3. The Economic Measures

In this regard, tax, charges or levies are the core economic instruments to address environmental objectives, whether under the system of government responsibility or producer responsibility. Both of these systems are the most widely used systems around the world. These systems ensure the required funds for an effective collection and utilisation of waste tyre in terms of exploiting their value (recycling or recovery technology). Both types of system seem to be able to achieve high recycling rates.

Implementing such economic measures in Global South counties such as Tunisia requires preventative measurements as the fact is, more often than not Global South countries such as Tunisia face with corruption-related issues and have some difficulties in controlling the activities at their borders, where smuggling activities are prominent. The solution to these issues can be achieved by simply removing duties on brand name tyres that are imported officially, which will make the smuggled tyres less lucrative. On the other hand, due to the current bureaucratic relationship between the Ministry of Environment and ANGED, waste management issues are not being addressed appropriately. This may be due to several reasons as presented by Hyden et al. (2003) in their study, who found that in the bureaucracy of Global South countries the hiring is rarely on merit, bureaucrats are seldom seen to be accountable, and the operations of the civil service often lack real transparency. The second point is that the relationship between rules and structures, on the one hand, and performance on the other, is difficult to establish. Therefore, this research proposes new sustainable organizational and financial models. In this case, it is ideal to appoint a single concessionaire (NGO-normally as a not-for-profit company) to carry out the function of producer responsibility, funded directly from tyre producers as members of this organisation. The

organization will thus enjoy a level of autonomy from the government (moves away from government bureaucracy), though it may be reporting directly to the Ministry in charge of Waste Management. The company should take the overall responsibility for organising a system to collect and dispose of waste tyres in Tunisia, in accordance with the legislation and regulations provisions, by contracting operating companies funded from the scheme revenue that arises from members of an organisation that represents tyre importers, tyre manufactures and vehicle importer agencies; the cost is eventually covered by a charge paid by the consumer when buying a new tyre.

6.3.4. Embracing the Informal Sector for Collection and Recycling of Waste Tyres

Recycling is a completely vital element of waste management (Ferrão et al., 2008), and currently, there is a scarcity or absence of formal recycling in Tunisia, except for one company in this field. As a result, the informal sector has taken up the obligation of filling the gap. There are no posted statistics on the collection and recycling rate in Tunisia; however, anecdotally the informal sector is helping to achieve collection and recycling. Nationally the government needs to enact a clear policy and strategy on tyre waste management and recycling that recognises the informal sector. Legislative changes that incorporate comprehensive policies and approaches to tyre waste management as a facet of SWM involving the informal sector would help to improve and boost the waste management system, create public awareness and improve attitudes towards waste (Ezeah et al., 2013). Therefore, the informal sector should specifically be involved to assist the collection of waste and recycling in the Tunisian context.

6.3.5. Education and Engagement

6.3.5.1. Greater Public Awareness of Waste Tyres

Awareness campaigns and public information about the new system should be carried out to make the new system of waste tyres understandable and acceptable to the citizens. The poor tyre waste situation can be partially dealt with through increasing public education and awareness campaigns of waste tyre issues. The campaigns could be integrated with a range of approaches adopted.

In this regard, the community-based approach could be adopted for public awareness. Greater awareness of waste tyre education could be achieved through the mosques and schools working closely with community gatekeepers, the ward heads and religious leaders. Whilst a comprehensive approach should be adopted to reach all of society the research has

shown that tyre producers mainly deal with vehicle owners for tyre replacement or repairing; therefore, some targeted campaigns could be developed to raise awareness, change behaviour and promote tyre waste recovery to benefit the environment.

There is a need for concerted national efforts through radio, television and newspapers to raise awareness among the general public. In Tunisia, the government in this regard still has a role in television and radio broadcasting. Nationally there are the National Public Television stations (Watanya 1 and Watanya 2) and there are four national public radio stations: (Radio Tunis, Radio Tunisia Culture, Radio Jeunes and RTCI). Being state-run these stations have minimal broadcasting costs and an effective strategy could be developed for publicising information to the public on waste. It should be noted that almost all Tunisians (99%) have at least one television and satellite device in their homes (Najla et al., 2015). Tunisia's education should introduce programmes on waste management and they should be an integral part of the fundamental curriculum, and universities and technical colleges must be encouraged to introduce programmes in the field of environmental management, including SWM courses, to train qualified personnel for this sector, in order to increase critical mass.

6.3.6. Increased Role of Tyre Waste Recovery

As acknowledged in this research, some of the recommendations require significant changes in the scope of the legislation, regulation, finance resources, education and engagement, as there is a low level of tyre recovery already underway in the study area. Thus, needs more to be done to promote tyre waste reduction based on the waste hierarchy. The research has used the systematic review of LCA for tyre waste as a means of assistance to the decision-making process in selecting the best technological alternative from an environmental perspective. The LCA for waste tyre indicates that all applications for car tyres recycling/recovery provide environmental benefits. Adopting the recycling/recovery is one of the priorities that are stated in the waste hierarchy, which gives an opportunity to build upon the existing behaviour in the community to help reduce the quantities of waste tyres that needs to be managed.

This research established as increasing tyre waste generation and complexity in the composition of tyre waste, as a result of an increase of vehicle fleet, population and urbanization. In order to solve this problem or improve on it, the government should pursue an alternative path that attempts to solve or reduce the problem. This can be done by

prohibiting tyre waste disposal at the landfills and promoting recycling and recovery processes.

6.3.7. Accompanying Measures

6.3.7.1. Public Authorities as Representatives in the Ministry of the Environment with other Affiliated Institutions and their Responsibilities

- Monitoring the execution of activities according to legislation and regulation, including contractual agreements.
- Monitoring tyre producer compliance with the new provisions in an acceptable manner.
- Monitoring and following up the collection of the fees or tax from the tyre producers for the benefit of the tyre waste management organisation.
- Monitoring and following up the implementation of the provisions of the law on violators of legislation and regulation.

6.3.7.2. The Obligations or Commitments of the Organisation (Not-For-Profit Company)

- Must be responsible for the collection of the fees or tax from the tyre producers.
- Achieve its goals within the duration of the planned time span.
- Periodic reporting to a public authority (National Agency for Waste Management) of the collection and treatment of waste tyres based on data collected from monitoring.
- The organisation should be responsible at every stage of the process, from the time the new tyres are imported or manufactured up to when the waste tyres are collected by their end facilitators (recovery companies).
- Must introduce standards for the products derived from waste tyres as key for their recognition as alternative energy sources or as secondary raw materials and to give payment for projects such as applying it in asphalt, turf, steel plants, thermoplastics etc. In this regard, the legislation must recognise this and address the need in order to avoid landfilling.
- Must report quantities and types of used/waste tyres received and types of treatment.
- It is fundamentally important for members in the organisation to transfer know-how of viable alternative technologies and participate with other research centres in Tunisia to develop research and development capacities that produce a high level of knowledge of viable alternative technologies.

6.4. Future Work

An important aspect of the research work required in the future is the investigation of public opinions and the willingness to participate in the waste tyre management programme. This could revolve around more qualitative exploration, engaging an array of actors and using other tools to collect data. A focus is also needed on estimating the quantity of waste tyre generated annually from all categories, adapting the model used here and expanding it to be more precise. In addition, this research also suggests that it would be beneficial for future work to further the exploration of the potential of LCA in the context of the environmental impacts associated with tyre waste recovery. This is important for a waste valorisation process and converting waste into more useful products in Tunisia is critical.

Ultimately, more work is needed to gather baseline data and to further our understanding of the complex nature of tyre waste issues in Tunisia. The methodological approach used here can be replicated in other countries (e.g. Libya) to yield similar results and provide an idea of the issues, and opportunities, in this area. Through doing so, the issue of tyre waste management in the Global South can be addressed and lessons learned from exemplars schemes, enabling countries to deal with this issues in a better way as populations and cities expand.

6.5. The Main Contribution of the Study

The main contribution of the research study represents in the following points:

- Revealing the informal tyre trade and mechanisms for dealing with this;
- Stats on the existing tyre issues;
- To build a foundation for sustainable tyre waste management system;
- To provide the basis for future research on the application of waste tyres as a source of valuable raw materials and mitigating the potential threats to the natural environment from stockpiling waste tyres in landfills.

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APPENDICES

Appendix 3.1 Checklist Questions Designed for an Interview with Institutions and NGO Bodies

Personal interviews for the purpose of data collection

- Briefly outlines the role and responsibilities of the guest's.
- A brief history of the organization?
- Request a brief description of your duties and responsibilities (section) or organization?

Current solid waste management system and particularly waste tyres

- Can you outline the current system of SWM in general in the city?
- Is this system included the management of waste tyres? What is your organization's participation in it?
- Are waste tyres is one of the environmental issues in the city?
- Do you think that current practices have created an environmental problem? (Air/water streams, public health and greenhouse gas emissions pollution, conserve resources).
- What policies are in place around tyre waste?
- How are you dealing with tyre waste presently? Do you Stockpile waste tyre at landfill sites?
- Do you have a defined programme for systematic waste tyre recycling in the near future?
- Do you have an established system of funding for Tunisia's tyre waste management program, funded by the private sector?
- To what extent do the bodies responsible for implementing SWM design/contribute to the policy themselves?
- Are there any new environmental policy plan?
- In general, does your organization have a role in deciding the new technologies? Explain?
- To what extent are environmental issues taken into consideration in decisions relating to waste management technologies?
- Are you familiar with any tyre waste technologies that could be socially or environmentally beneficial?
- What in your view would be the barriers to adopting waste tyre technologies in Tunisia?

♦ Cost of purchase/maintenance

♦ Public attitudes

♦ Lack of local/national governmental support

♦ Policy for SWM

♦ Environmental protection regulations

♦ Training required to operate/repair

♦ Lack of familiarity with the technology (Information)

♦ Lack of infrastructure

♦ Difficult to locate

♦ Others

Appendix 3.2 Checklist Questions Designed for Interview with Private Sectors

Interview with tyre dealers, shops and garage

Site: (Name, Type, Location)	
Date	
Interviewee: (Name, Title)	
Interviewer(s):	

- Do you accept old tyres from your customers in exchange for the ones you supply?
- What do you do with the waste tyre that you collect "accepted from customer" and why do you do that?
- Does the customer pay you to accept old waste tyres?
- How many tyres are handled at this facility? - Annually, weekly, daily.
- Do you familiar with waste tyres causes an environmental problem with mismanagement practices? (Pollution of air/waterways, public health, greenhouse gas emissions, conserving resources).
- Do you think having tyres collection skips at local centers could reduce illegal tyres dumping?
- What do you think about waste tyre management in Tunisia – policy, law and regulation in place that applied?
- Do you pay a tax for waste that you generate, previously or presently?

Appendix 3.3 Checklist Questions Designed For an Interview with an Informal Waste Collector

Site: (Name, Type, Location)	
Date:	
Interviewee: (Name, Title)	
Interviewer(s):	

1. How long have you worked as a waste tyre collector? ……... ..... (Years/months)

2. What equipment/tools do you work with?

3. Who are your clients and how do you charge for your service?

4. Where do you dispose of the waste you collect from your clients?

5. Would you like to be employed by the waste department to do this same work?

• Yes, I would [ ] why? ……..……..

• No, I wouldn't [ ] why not? ……..

6. Are you a native of this city?

• Yes [ ]

• No [ ] where do you originally come from?

7. Do you have anything else to say about your work or a question to ask with regard to this discussion.

Appendix 3.4 Participant Letter of Invitation

University of Salford MANCHESTER

School of Environment & Life Science
The Crecent, Salford, Lancashire M5 4WT

Participant Letter of Invitation

Project title	Extrapolation of Fact on Environmental Impact and Waste Management of Used Tyres: Evaluating the Libya / Tunisia Context
Researcher	**Name:** Munir Abuzukhar **Email address:** m.abuzukhar@edu.salford.ac.uk **Contact telephone number:**

16/11/2015

Dear Sir or Madam

This is a letter of invitation to inquire if you would like to take part in a postgraduate research project regarding analyse the sustainability of the waste tyre management system in cities through an interview. Before you decide if you would like to take part it is important for you to understand why the project is being undertaken and what it will involve. Please take time to carefully read the Participant Information Sheet on the following pages and discuss it with others if you wish. Ask me if there is anything that is not clear, or if you would like more information. If you would like to take part, please complete and return the Informed Consent Declaration form.

Please do not hesitate to contact me if you have any questions.

Yours faithfully,

Munir Abuzukhar

Appendix 3.5 Observation Checklist

Observation checklists it is assisting an observer to identify the behaviour practices of the waste tyres disposal problem in the community.

Description of the Tool: The researcher developed the observational checklist for practices of disposal of the waste tyre in the capital of Tunisia at Tunis. It consists of a range of content in the checklist. The checklist contents if implemented takes yes, no or n/b.

Project : Site Location :

Filed observation Date :

Field observation contents		Implemented?		N/A	**Remarks** (i.e. specify a location, good/bad practices, a problem observed, a possible cause of nonconformity and/or proposed corrective)
		Yes	No		
Sl.no				**Code:**	
1.	**Waste tyre disposal practices by tyre dealers and scrap vehicle dealers.**				
1.1.	Are tyre dealers accepted old tyres from customers?				
1.2.	Are tyre dealers posed a levied on customers for the disposal of old tyres (waste tyre)?				
1.3.	Are tyre dealers documented and recorded of old tyres (waste tyre) that accepted?				
1.4.	Are tyre dealers stored old tyres secured place?				
1.5.	Are the storage place of the waste tyre fenced?				
1.6.	Are waste tyre storage classified and numbered?				
1.7.	Are tyre dealer's shows sign to prevent fire as a policy procedure?				
1.8.	Are there extinguishing unit available at storage area for tyres?				
1.9.	Are tyre dealers presented leaflet regarding the consumer awareness campaign of tyres and rims purchased?				
1.10.	Are the tyres removed from scrap vehicles?				
2.	**Disposal of the waste tyre in the landfill or open environment**				
2.1.	Are separated areas provided for tyre storage (Monofill)?				
2.2.	Are waste tyre mixed with municipal waste?				
2.3.	Are tyre wastes removed off-site regularly?				
2.4.	Are waste tyres disposed of in the open environment?				
2.5.	Is there an environmental problem in terms of (Pollution of air/waterways and soil) caused by waste tyre mismanagement practices?				
2.6.	Are there local fire service near to stake piles storage of tyres				

Appendix 3.6 The General Search Terms Scoping and Evaluation Used in Systematic Review of Life Cycle Assessment for Waste Tyre

WEB SEARCH: WEB OF SCIENCE ALL DATABASE				
S.N	**SEARCH STRING**	**NUMBER OF HITS**	**CHANGES FROM PREVIOUS**	**DATE OF SEARCH**
0	**You searched for: (TS=(("LCA" OR "environment* impact" OR "treat* impact") AND ("waste tyre" OR "waste tyre" OR "scrap tyre" OR "scrap tyre" OR "rubber tyre" OR "rubber tyre" OR "end-of-life tyre" OR "end-of-life tyre"))) AND LANGUAGE: (English)** **Timespan: 2006-2017. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.**	**20**		**01/08/2017**
1	TITLE: (*Life Cycle*) AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scrap tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end of life tyre) OR TITLE: (end of life tyre) Refined by: PUBLICATION YEARS: (2016 OR 2014 OR 2008 OR 2017 OR 2015 OR 2012 OR 2009 OR 2006 OR 2013 OR 2011 OR 2010 OR 2007) AND DOCUMENT TYPES: (ARTICLE OR REVIEW OR ABSTRACT) AND LANGUAGES: (ENGLISH) Timespan: 2006-2017. Search language=Auto	1,010	n/a	
2	TITLE: (*Life cycle tyre assessment*) OR TITLE: (*Life Cycle tyre analysis*) OR TITLE: (*Life Cycle tyre evaluation*) OR TITLE: (Environment impact analysis) AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scrap tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end of life tyre) OR TITLE: (end of life tyre) Refined by: LANGUAGES: (ENGLISH) AND DOCUMENT TYPES: (ARTICLE OR REVIEW OR ABSTRACT) Timespan: 2006-2017. Search language=Auto	1,013	amendment in the sentence with keeping the phrase of (life cycle)	
3	TITLE: (assessing the environmental impact) OR TITLE: (evaluating the environmental impact) OR TITLE: (analysing the environmental impact) AND TITLE: (tyre waste) AND TITLE: (tyre waste) OR TITLE: (scrap tyre) OR TITLE: (scarp tyre) OR TITLE: (life cycle assessment) OR TITLE: (life cycle analysis) Refined by: DOCUMENT TYPES: (ARTICLE OR REVIEW) AND LANGUAGES: (ENGLISH) Timespan: 2006-2017. Search language=Auto	4,723		
4	TITLE: ("assessing the environmental impact") OR TITLE: ("evaluating the environmental impact") OR TITLE: ("analysing the environmental impact") AND TITLE: (tyre waste) AND TITLE: (tyre waste) OR TITLE: (scrap tyre) OR TITLE: (scarp tyre) OR TITLE: (life cycle assessment) OR TITLE: (life cycle analysis)	4,547		

	Refined by: DOCUMENT TYPES: (ARTICLE OR REVIEW) AND LANGUAGES: (ENGLISH) Timespan: 2006-2017. Search language=Auto			
5	TITLE: (comparison Life Cycle Assess*) OR TITLE: (comparison life cycle analys*) OR TITLE: (comparison life cycle evaluat*) AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scarp tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end-of-life tyre) OR TITLE: (end-of-life tyre) Refined by: LANGUAGES: (ENGLISH) Timespan: 2006-2017. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.	1,313	The same above phrase with adding sentence OR (*comparison life cycle analysis*)	
6	TITLE: (comparison Life Cycle Assessment*) OR TITLE: (comparison life cycle analysis*) OR TITLE: (comparison life cycle evaluation*) AND TITLE: (waste tyre manag* option) OR TITLE: (waste tyre manag* option) OR TITLE: (scrap tyre manag* option) OR TITLE: (scarp tyre manag* option) OR TITLE: (rubber tyre manag* option) OR TITLE: (rubber tyre manag* option) OR TITLE: (end-of-life tyre manag* option) OR TITLE: (end-of-life tyre manag* option) Refined by: LANGUAGES: (ENGLISH) Timespan: 2006-2017. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.	157	Still the same above phrase with adding terms (management option)	
7	You searched for: TITLE: (Life cycle assess*) OR TITLE: (life cycle analys*) OR TITLE: (life cycle evaluate*) AND TITLE: (waste tyre manag*) OR TITLE: (waste tyre manag*) OR TITLE: (scrap tyre manag*) OR TITLE: (scrap tyre manag*) OR TITLE: (rubber tyre manag*) OR TITLE: (rubber tyre manag*) OR TITLE: (end-of-life tyre manag*) OR TITLE: (end-of-life tyre manag*) Refined by: LANGUAGES: (ENGLISH) Timespan: 2006-2017. Search language=Auto	5,466		
8	You searched for: TITLE: ("Life cycle assess*") AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scrap tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end of life tyre) OR TITLE: (end of life tyre) Timespan: 2006-2017. Search language=English	1,316		
9	TITLE: (LCA*) OR TITLE: (Life cycle evaluat*) OR TITLE: (Life cycle analys*) OR TITLE: (Life Cycle Assess*) OR TITLE: (environmental impact) AND TITLE: (manag* waste tyre) OR TITLE: (manag* waste tyre) OR TITLE: (manag* scrap tyre) OR TITLE: (manag* scrap tyre) OR TITLE: (manag* rubber tyre) OR TITLE: (manag* rubber tyre) OR TITLE: (manag* end-of-life tyre) OR TITLE: (manag* end-of-life tyre) Timespan: 2006-2017. Search language=English	7,567		
10	TITLE: (Life cycle evaluate*) OR TITLE: (Life cycle analyse*) OR TITLE: (Life Cycle Assess*) AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scrap tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end-of-life tyre) OR TITLE: (end-of-life tyre) Timespan: 2006-2017. Search language=English	1,424		

11	TITLE: ("LCA") OR TITLE: ("environmental* impact") AND TITLE: (waste tyre) OR TITLE: (waste tyre) OR TITLE: (scrap tyre) OR TITLE: (scrap tyre) OR TITLE: (rubber tyre) OR TITLE: (rubber tyre) OR TITLE: (end-of-life tyre) OR TITLE: (end-of-life tyre) Refined by: PUBLICATION YEARS: (2016 OR 2012 OR 2009 OR 2007 OR 2015 OR 2011 OR 2017 OR 2006 OR 2014 OR 2010 OR 2008 OR 2013) AND DOCUMENT TYPES: (ARTICLE OR REVIEW) AND DOCUMENT TYPES: (ARTICLE OR REVIEW) AND DOCUMENT TYPES: (ARTICLE OR ABSTRACT OR REVIEW) AND LANGUAGES: (ENGLISH) Timespan: 2006-2017. Search language=Auto / Articles and Review	1,977		

WEB SEARCH : SCIENCE DIRECT

S.N	SEARCH STRING	NUMBER OF HITS	CHANGES FROM PREVIOUS	DATE OF SEARCH
0	**Title-Abstr-Key (("LCA" OR "environment* impact" OR "treat* impact") AND ("waste tyre" OR "waste tyre" OR "scrap tyre" OR "scrap tyre" OR "rubber tyre" OR "rubber tyre" OR "end-of-life tyre" OR "end-of-life tyre")).**	**25**		
1	**TITLE-ABSTR-KEY(*Life Cycle*) and TITLE-ABSTR-KEY(waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end of life tyre OR end of life tyre).**	**11**		**04/07/2017**
2	**ALL(*Life cycle tyre assessment* OR *Life Cycle tyre analysis* OR *Life Cycle tyre evaluation* OR Environment impact analysis) and ALL(waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end of life tyre OR end of life tyre).**	**1,269**		
3	**ALL(assessing the environmental impact OR evaluating the environmental impact OR analysing the environmental impact) and ALL(tyre waste OR tyre waste OR scrap tyre OR scarp tyre AND life cycle assessment OR life cycle analysis).**	**921**		
4	**ALL("assessing the environmental impact" OR "evaluating the environmental impact" OR "analysing the environmental impact") and ALL(tyre waste OR tyre waste OR scrap tyre OR scarp tyre AND life cycle assessment OR life cycle analysis).**	**813**		
5	**ALL(comparison Life Cycle Assess* OR comparison life cycle analys* OR comparison life cycle evaluat*) and ALL(waste tyre OR waste tyre OR scrap tyre OR scarp tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre).**	**980**		
6	**ALL(comparison Life Cycle Assessment* OR comparison Life Cycle Analysis* OR comparison Life Cycle Evaluation*) and ALL(waste tyre manag* option OR waste tyre manag*option OR scrap tyre**	**73**		

	manag* option OR scrap tyre manag* option OR rubber tyre manag* option OR rubber tyre manag*			
7	**ALL(Life cycle assess* OR life cycle analys* OR life cycle evaluate*) and ALL(waste tyre manag* OR waste tyre manag* OR scrap tyre manag* OR scrap tyre manag* OR rubber tyre manag* OR rubber tyre manag* OR end-of-life tyre manag* OR end-of-life tyre manag*). Sereach with: All/ 2006-2017 /language English**	**893**		
8	**TITLE-ABSTR-KEY("Life Cycle assess*") and TITLE-ABSTR-KEY(waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end of life tyre OR end of life tyre). Sereach with: Journal / sereach with: Article title , Abstract, Keyword/ 2006-2017 /language**	**5**		
9	**ALL(LCA* OR Life cycle evaluat* OR Life cycle analys* OR Life Cycle Assess* OR environmental impact) and ALL(manag* waste tyre OR manag* waste tyre OR manag* scrap tyre OR manag* scrap tyre OR manag* rubber tyre OR manag* rubber tyre OR manag* end-of-life tyre OR manag* end-of-life**	**116**		**21/07/2017**
10	**ALL(Life cycle evaluat* OR Life cycle analys* OR Life Cycle Assess*) and ALL(waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre). Journal/ All/ English/ 2006-2017**	**1,349**		
11	**TITLE-ABSTR-KEY("LCA" OR "environmental* impact") and TITLE-ABSTR-KEY(waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre) Limited to: TITLE-ABSTR-KEY/ English/ 2006-2017**	**27**		
WEB SEARCH : GOOGLE SCHOLAR				
S.N	**SEARCH STRING**	**NUMBER OF HITS**	**CHANGES FROM PREVIOUS**	**DATE OF SEARCH**
0	**"LCA" OR "environmental* impact" OR “treat* impact” AND "waste tyre" OR "waste tire" OR "scrap tyre" OR "scrap tire" OR "rubber tyre" OR "rubber tire" OR "end-of-life tyre" OR "end-of-life tire" – Limited to Custom range 2006-2017 and English language.**	**445 522 On 31.12.2017**		
1	***Life Cycle* AND waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end of life tyre OR end of life tyre Anywhere in articles / 2006-2017/ language English**	**11,500**		
2	***Life cycle tyre assessment* OR *Life Cycle tyre analysis* OR *Life Cycle tyre evaluation* OR Environment impact analysis AND waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber**	**3,700**		

	tyre OR rubber tyre OR end of life tyre OR end of life tyre **Anywhere in articles / 2006-2017/ language English**			
3	**assessing the environmental impact OR evaluating the environmental impact OR analysing the environmental impact AND tyre waste OR tyre waste OR scrap tyre OR scarp tyre AND life cycle assessment OR life cycle analysis** **Anywhere in articles / 2006-2017/ language English**	**5,180**		
4	**“assessing the environmental impact” OR “evaluating the environmental impact” OR “analysing the environmental impact” AND tyre waste OR tyre waste OR scrap tyre OR scrap tyre AND life cycle assessment OR life cycle analysis** **Anywhere in articles / 2006-2017/ language English**	**67**		
5	**comparison Life Cycle Assess* OR comparison life cycle analys* OR comparison life cycle evaluate* AND waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre** **Anywhere in articles / 2006-2017/ language English**	**3,140**		
6	**comparison Life Cycle Assessment* OR comparison Life Cycle Analysis* OR comparison Life Cycle Evaluation* AND waste tyre manag* option OR waste tyre manag*option OR scrap tyre manag* option OR scrap tyre manag* option OR rubber tyre manag* option OR rubber**	**12,000**		
7	**Life cycle assess* OR life cycle analysis* OR life cycle evaluate* AND waste tyre manag* OR waste tyre manag* OR scrap tyre manag* OR scrap tyre manag* OR rubber tyre manag* OR rubber tyre manag* OR end-of-life tyre manag* OR end-of-life tyre manag*** **Anywhere in articles / 2006-2017/ language English**	**16,000**		
8	**"Life Cycle assess*" AND waste tyre OR waste tire OR scrap tyre OR scrap tire OR rubber tyre OR rubber tire OR end of life tyre OR end of life tire** **Anywhere in articles / 2006-2017/ language English**	**82**		
9	**LCA* OR Life cycle evaluat* OR Life cycle analys* OR Life Cycle Assess* OR environmental impact AND manag* waste tyre OR manag* waste tyre OR manag* scrap tyre OR manag* scrap tyre OR manag* rubber tyre OR manag* rubber tyre OR manag* end-of-life tyre OR manag* end-of-life tyre** **Anywhere in articles / 2006-2017/ language English**	**168**		
10	**Life cycle evaluate* OR Life cycle analyse* OR Life Cycle Assess* AND waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre** **Anywhere in articles / 2006-2017/ language English**	**2,610**		

11	"LCA" OR "environmental* impact" AND waste tyre OR waste tyre OR scrap tyre OR scrap tyre OR rubber tyre OR rubber tyre OR end-of-life tyre OR end-of-life tyre Anywhere / English/ 2006-2017	553 564 on 31.07.2017 about 1,310 results on 31.12.2017		
WEB SEARCH : SCOPUS				
S.N	**SEARCH STRING**	**NUMBER OF HITS**	**CHANGES FROM PREVIOUS**	**DATE OF SEARCH**
0	TITLE-ABS-KEY ("LCA" OR "environmental* impact" OR "treat* impact" AND "waste tyre" OR "waste tire" OR "scrap tyre" OR "scrap tire" OR "rubber tyre" OR "rubber tire" OR "end-of-life tyre" OR "end-of-life tire") AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))	69		
1	(TITLE-ABS-KEY (*life AND cycle*) AND TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end AND of AND life AND tyre) OR TITLE-ABS-KEY (end AND of AND life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))	56		
2	(TITLE-ABS-KEY (*life AND cycle AND tyre AND assessment*) OR TITLE-ABS-KEY (*life AND cycle AND tyre AND analysis*) OR TITLE-ABS-KEY (*life AND cycle AND tyre AND evaluation*) OR TITLE-ABS-KEY (environment AND impact AND analysis) AND TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-	75		

	KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end AND of AND life AND tyre) OR TITLE-ABS-KEY (end AND of AND life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))			
3	**(TITLE-ABS-KEY (assessing AND the AND environmental AND impact) OR TITLE-ABS-KEY (evaluating AND the AND environmental AND impact) OR TITLE-ABS-KEY (analysing AND the AND environmental AND impact) AND TITLE-ABS-KEY (tyre AND waste) OR TITLE-ABS-KEY (tyre AND waste) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scarp AND tyre) OR TITLE-ABS-KEY (life AND cycle AND assessment) OR TITLE-ABS-KEY (life AND cycle AND analysis)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))**	**1,199**		
4	**(TITLE-ABS-KEY ("assessing the environmental impact") OR TITLE-ABS-KEY ("evaluating the environmental impact") OR TITLE-ABS-KEY ("analysing the environmental impact") AND TITLE-ABS-KEY (tyre AND waste) OR TITLE-ABS-KEY (tyre AND waste) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scarp AND tyre) OR TITLE-ABS-KEY (life AND cycle AND assessment) OR TITLE-ABS-KEY (life AND cycle AND analysis)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))**	**116**		
5	**(TITLE-ABS-KEY (comparison AND life AND cycle AND assess*) OR TITLE-ABS-KEY (comparison AND life AND cycle AND analys*) OR TITLE-ABS-KEY (comparison AND life AND cycle AND evalu at*) AND TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))**	**6**		

6	**(TITLE-ABS-KEY (comparison AND life AND cycle AND assessment*) OR TITLE-ABS-KEY (comparison AND life AND cycle AND analysis*) OR TITLE-ABS-KEY (comparison AND life AND cycle AND evaluation*) AND TITLE-ABS-KEY (waste AND tyre AND manag* AND option) OR TITLE-ABS-KEY (waste AND tyre AND manag* AND option) OR TITLE-ABS-KEY (scrap AND tyre AND manag*option) OR TITLE-ABS-KEY (scrap AND tyre AND manag* AND option) OR TITLE-ABS-KEY (rubber AND tyre AND manag*option) OR TITLE-ABS-KEY (rubber AND tyre AND manag* AND option) OR TITLE-ABS-KEY (endocrine AND tyre AND manag* AND option) OR TITLE-ABS-KEY (endocrine AND tyre AND manag* AND option)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005**	**2**		
7	**(TITLE-ABS-KEY ("Life cycle assess*") OR TITLE-ABS-KEY (life AND cycle AND analys*) OR TITLE-ABS-KEY (life AND cycle AND evaluate*) AND TITLE-ABS-KEY (waste AND tyre AND manag*) OR TITLE-ABS-KEY (waste AND tyre AND manag*) OR TITLE-ABS-KEY (scrap AND tyre AND manag*) OR TITLE-ABS-KEY (scrap AND tyre AND manag*) OR TITLE-ABS-KEY (rubber AND tyre AND manag*) OR TITLE-ABS-KEY (rubber AND tyre AND manag*) OR TITLE-ABS-KEY (end-of-life AND tyre AND manag*) OR TITLE-ABS-KEY (end-of-life AND tyre AND manag*)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005**	**25**		
8	**(TITLE-ABS-KEY ("Life cycle assess*") AND TITLE-ABS KEY (waste AND tyre) OR TITLE-ABS KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end AND of AND life AND tyre) OR TITLE-ABS KEY (end AND of AND life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005**	**23**		
9	**(TITLE-ABS-KEY (lca*) OR TITLE-ABS-KEY (life AND cycle AND evaluat*) OR TITLE-ABS KEY (life AND cycle AND analys*) OR TITLE-ABS-KEY (life AND cycle AND assess*) OR TITLE-ABS-KEY (environmental AND impact) AND TITLE-ABS-KEY (manag* AND waste AND tyre) OR TITLE-ABS-KEY (manag* AND waste AND tyre) OR TITLE-ABS-KEY (manag* AND scrap AND tyre) OR TITLE-ABS-KEY (manag* AND scrap AND tyre) OR TITLE-ABS-KEY (manag* AND rubber AND tyre) OR TITLE-ABS-**	**64**		

	KEY (manag* AND rubber AND tyre) OR TITLE-ABS-KEY (manag* AND end-of-life AND tyre) OR TITLE-ABS-KEY (manag* AND end-of-life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005			
10	**(TITLE-ABS-KEY ("Life cycle evaluate*") OR TITLE-ABS-KEY ("Life cycle analys*") OR TITLE-ABS-KEY ("Life Cycle Assess*") AND TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))**	**31**		
11	**(TITLE-ABS-KEY ("LCA") OR TITLE-ABS-KEY ("environmental* impact") AND TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (waste AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (scrap AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (rubber AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre) OR TITLE-ABS-KEY (end-of-life AND tyre)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2005 AND (LIMIT-TO (LANGUAGE , "English"))** **Limited to: document type: Articles and review / field: TITLE-ABS-KEY/ English / 2006-2017**	**116**		

Appendix 3.7 Study Eligibility Form

Item	Yes (Go to next Question)	Unclear (Go to next Question)	No (Excluded)
Study Type: • Is the study a peer reviewed journal published between 2006-2017? • Is the study in English Language?			
Participants in the study: Were the participants in the study is a reuse, recycling, recovery and landfill of the waste tyre.			
Intervention(s) in the study in terms of environmental impact either at midpoint or endpoint: Did intervention(s) include assessment of environmental impact categories represented on the damage human health, ecosystem Quality and/or resource depletion?			
Outcome of the study Did the outcome include evidence of implementation of life cycle assessment or evaluation or analysis and/ or other relevant of environmental analysis or environmental load; evidence of addressing waste or scrap or rubber or ground or end of life tyres; evidence of method to evaluate an environmental impact.			

Appendix 3.8 Data Extraction Form

Does this study meet all the inclusion criteria?	
General characteristics	**Metadata of the studies** □ It is a study related to life cycle assessment of waste tyre in an international context. □ The studies were published between period 2006-2017. □This paper is peer reviewed.
Standard compliance Characterisation of how ISO standard was handled	Do the standards-related statement mentioned (used in text for method description)
Goals and scope of study clearly defined in terms of: • Object of study • Functional unit • System boundaries	It is a study covered the type of pre-treatments, treatments and system components. Did stated and defined as an equal amount of product or equivalent service Yes No Did study included and excluded processes in assessment Yes No
Geographical scope	Did the location of the LCA of waste tyre under study was reported
Impact coverage	Did the Impact categories are covered in assessment?
Life cycle inventory (LCI) analysis	Input and output data and sources of data used (Primary and secondary data)
Results and interpretation	**Main findings, uncertainty and sensitivity analyses**

Appendix 3.9 Ethical Approval Panel

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

7 September 2016

Munir Abuzukhar

Dear Munir

RE: ETHICS APPLICATION ST 15-62 – Extrapolation of Fact on Environmental Impact and Waste Management of Used Tyres: Evaluating the Tunisian Context

Based on the information you provided, I am pleased to inform you that your application ST 15-62 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management,
School of Built Environment
University of Salford
Maxwell Building, The Crescent
Greater Manchester, UK M5 4WT
Phone: + 44 161 295 6829
Email: m.arif@salford.ac.uk