The Rubber Industry and Extended Producers Responsibility Framework

"Opportunities and Threats for Swedish Rubber Manufacturers"

Master's Thesis

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Abstract

An array of sustainable ways either to reduce the amount of waste rubber generated or for the re-utilization of waste rubber products as different means of resources at the end of their service lives are provided and briefly evaluated from economic, social and environmental perspectives. Additionally, potential measures that the Swedish Rubber Industry and its major stakeholders can implement, as an Extended Producer's Responsibility (EPR), to increase source reduction, reuse, material recycling of, and energy recovery from waste rubber are examined.

To understand and evaluate the options for achieving a sustainable waste rubber management system in Sweden, the causal loop approach is used. Based on the concept of system dynamics, the links between different issues, possible problems arising from them and the solutions, and their relation to sustainable waste rubber management system are analyzed by understanding the cause and effect relationship between important parameters. A model is developed by using software called Stella 5.1.1u in order to help the decision-makers to evaluate different scenarios in Swedish waste rubber management.

Having addressed and analyzed the possible options in the management of waste rubber, source reduction/waste prevention is considered to be the most desirable option. Additionally, retreading and material recycling are two other areas, which can bring significant environmental, economic and social potential benefits.

Therefore, in order to bring the Swedish rubber industry to a well prepared position to deal with the problems related to waste rubber in a more sustainable way there is a need for active participation and co-operation of all major stakeholders to promote retreading of used tires and recycling of waste rubber instead of focusing too much on energy content recovery, and to pay more attention to the establishment of a waste management system (similar to the one for scrap tires) for collection and handling of industrial rubber products.

Key words;
Waste rubber management, systems dynamics, extended producers responsibility, source reduction, material recycling and *retreading.*

List of Acronyms

American Society for Testing and Material	ASTM
Bureau des Industries du Caoutchouc	BLIC
Bus Tires	BTs
Butadiene Rubber	BR
Design for Environment	DFE
End of Life Vehicle Legislation	ELV
European Commission	EC
European Tire Recycling Association	ETRA
European Union	EU
Extended Producers Responsibility	EPR
Industrial Rubber Products	IRPs
Isoprene Rubber	IR
Lorries	Ls
Lorry Tires	LTs
North American Rubber Recyclers' Association	NARRA
Other Vehicle Tires	OVTs
Passenger Car Tires	PCTs
Passenger Cars	PCs
Products of Incomplete Combustion	PICs
Styrene Butadiene Rubber	SBR
Swedish National Road Administration's	SNRA
Swedish Rubber Manufacturers Association	SRMA
Svensk Däckåtervinning AB	SDAB
Thermoplastic Elastomers	TPEs
Tire derived Fuel	TDF
Total Scrap Tires	TSTs
Total Waste Rubber	TWR
Volatile Organic Compounds	VOCs

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CHAPTER 1

INTRODUCTION

1.1. Background

Rubber has an essential role in today's society. Rubber industry can be divided into two main sectors, namely *tire manufacturers* and *industrial rubber manufacturers* and produce a wide variety of products that people commonly rely on in their daily life. They are used either as tires on cars, as sealing material on windows or as hoses with which flowers are watered in gardens.

By far, automotive industry is the most important market for both tires and other industrial rubber products[1]. In Sweden, over the last three decades, the number of vehicles have approximately doubled and further increases are expected over the next decade[2&3]. This trend will ultimately increase the consumption of rubber products, which will also increase the use of non-renewable resources, emissions to the air, water and soil during their manufacturing and usage stages[4].

The life cycle of rubber products starts with the harvesting of the virgin rubber. If the product is produced from synthetic rubber then the chemicals are produced, otherwise the rubber plant is processed. After being vulcanized (See Section 2.1.1) as part of product manufacturing process, finished rubber products become ready for delivery. The products are sent via different distribution channels for consumer purchase. Once these rubber products have been used and reached the end of their useful lives, they enter the scrap and recycling stream. The chain that extends from raw material suppliers to landfills or recycling and recovery plants forms the physical route along which raw materials and rubber products travel and cause impacts on the environment.

Today, the final stage of product chain, disposal of waste rubber (especially scrap tires) has become a severe environmental problem[5]. Rubber industry is facing an increasing pressure from different stakeholders including society, authorities and customers (mainly automotive industry) regarding the potential impact of waste rubber on humans and the natural environment. They are further pushed to explore possibilities of different sustainable ways of recovering post consumer waste rubber products as resources at the end of their service lives. Moreover, there is also a growing interest in the development of economically viable reduction/recycling operations of waste rubber, mainly due to their occurrence in considerable quantities. Hence, there is a need to examine closely the opportunities and challenges for Swedish rubber industry regarding these developments in the field of waste rubber management and assist them to ensure the long term sustainable management of waste rubber in which social development, environmental conservation and economic benefits are balanced.

1.2 Objectives

The main objectives of this study are:

1) To provide an array of sustainable ways either to reduce the amount of waste rubber generated or for the re-utilization of waste rubber products as different means of resources at the end of their service lives and briefly evaluate these options from economic, social and environmental perspectives.

2) To examine potential measures that the Swedish Rubber Industry and its major stakeholders can implement, as an Extended Producer's Responsibility (EPR), to increase source reduction, reuse, material recycling of, and energy recovery from waste rubber.

1.3 Methodology

The methodology followed in the research work includes firstly a literature study to develop a better understanding of rubber production. To enforce the theoretical background regarding manufacturing processes with practical experience site visits at Trelleborg AB rubber plant was conducted. Identification of different options in waste rubber management was carried out through desktop research (university and industry libraries, internet sources) along with telephone and personal interviews with industry leaders as long as other site visits. Such options were further analyzed by examining their economic, social and environmental benefits and drawbacks.

After examining all the relevant literature, consulting the experts and compiling the information needed, *system dynamics approach* is utilized and a *causal loops diagram* (See Section 5.2) is built to better understand and illustrate how different parameters and actors in the management of waste rubber integrate and interact. To facilitate the estimation of different outcomes of such integration and interactions under various expected circumstances a simulation model is developed using Stella 5.1.1u software (High Performance Systems Inc., Hanover, NH, USA). This model is run for 7 different scenarios that correspond to various future conditions that have a probability to occur, in the coming 20 years. Based on the results of such simulations conclusions were drawn.

1.4 Scope & Limitations

Due to the fact that scrap tires represent the vast majority of post consumer waste rubber, the focus of this study is on this product group. Such a choice can further be justified by the fact that the chosen product group is the only one for which there exists an established waste management system. However, as all other large volume waste industrial rubber products can be managed using similar approaches highlighted in this work, the findings of this thesis will also be applicable for such wastes once a system for their management is established.

In order to find out an exact answer to the question *"Which one of the waste rubber management practices is the best?"* a detailed life cycle analysis, which lies outside the scope of this thesis is needed. Instead, different alternatives for dealing with waste rubber are identified and compared in terms of their environmental, social and economical advantages and disadvantages without getting into specific details.

Since there are several different material recycling technologies and methods, which are too extensive to cover in this paper, they are not discussed in detail. Instead, they are referred to further readings.

Data used in building the model and running the model for different scenarios are mainly based on officially published data and projections. At the point where there is no accessible data, estimations and/or assumptions are made.

1.5. Paper Outline

This paper is presented in five chapters. In the first chapter a brief introduction, followed by objectives of the study is given. The methodology used in the study, scope, and limitations faced are also represented in this chapter.

Chapter two presents the manufacturing of rubber products and describes the raw materials used in production.

Chapter three analyses different options in waste rubber management along with a comparison of these alternatives regarding their environmental, economic and social advantages, and disadvantages.

Chapter four reviews the present situation regarding the fate of rubber as waste. After presenting the current progresses with waste rubber in Sweden, relevant legislation and regulations, major stakeholders and their roles in Swedish rubber industry are analyzed.

Chapter five includes the presentation of causal loop diagrams and introduces the model that is used to analyze different scenarios. With a brief introduction and the understanding of the causal loop diagram, different parts of the model are described. Additionally, seven different scenario analyses are compared to each other and followed by a conclusion.

In the last chapter of the paper, a general conclusion of the study is given.

CHAPTER 2

UNDERSTANDING OF RUBBER PRODUCTION

Before discussing alternative ways for dealing with waste rubber in the following chapter, this chapter aims to give brief descriptions of raw materials used in rubber production and develop an understanding of different stages in the manufacturing processes.

2.1 Raw Materials

Rubber compound that is used in the manufacturing of various rubber products, is a mixture of natural and/or synthetic rubber with different chemical additives[6].

2.1.1 Natural Rubber

Latex, a suspension of isoprene polymers, is the sap extracted from a variety of vegetation, mainly the rubber tree known as *Havea brasiliensis*. It is a mixture of water (62%), rubber particles (35%) and several other ingredients of which protein is one of the most important. Around these very tiny rubber particles, there is a very thin layer of proteins, which does not allow rubber particles to lump together. By adding acid to the latex, the protein layer is broken and the polymers are coagulated[4&6].

Natural rubber extracted by this way is brittle at low temperatures and tacky at high temperatures. For that reason it was not used commercially until 1839, when it was accidentally discovered that by heating rubber and sulfur together at a high pressure these negative properties disappeared and the material had changed to become elastic. With this process, called ***vulcanization***, rubber production started to become a real commercial industry. Unvulcanized rubber, since the molecules can move against each other, has a plastic behavior similar to chewing gum. Under a stress, it can be permanently deformed. By vulcanization, sulfur forms new chemical bonds between the polymer molecules which give rubber the typical properties such that, strong, elastic, impermeable to gases and resistant to abrasion, chemical action, heat and electricity[4&6].

Total world production of natural rubber in 1997 was 6.4 million tones[4]. Today the main producers of natural rubber are Thailand, Indonesia and Malaysia, which supplies 80% of the world natural rubber consumption[7]. Almost all of the natural rubber production is used for tire manufacturing.

2.1.2 Synthetic Rubber

Today, there are various chemically manufactured synthetic rubbers, which have many properties comparable with natural rubber. Among the many other special types, Styrene-butadiene rubber (SBR), Isoprene rubber (IR), Butadiene rubber (BR) are the ones so called general purpose synthetic rubbers. Properties of different synthetic rubber types including natural rubber are compared in Table 2.1 in Appendix 1.

More than 60% of the World's 16.7 million tones of rubber consumption in 1997 was synthetic rubber[4]. It's primarily manufactured at chemical plants in industrial Europe and the USA. As in the case of natural rubber consumption, tire manufacturers are the biggest consumers of synthetic rubber in the world.

2.1.3 Other Raw Materials

Additional to natural and/or synthetic rubber, some other additives are used to form rubber compound, which is used for manufacturing of various rubber products. These additives and their usage purposes are as follows;

- ***Fillers*:** Most rubber products contain filler, such as carbon black, silica, clay or whiting. Although, in the beginning they were used to reduce the cost of the compound, the main role of the filler is to tailor the properties of the final product. Carbon black, which is made from crude oil or gas, is used to reinforce the rubber compound, where whiting or clay can be used to extend the compound.
- ***Vulcanizing agents*:** In addition to natural and/or synthetic rubber and fillers, a rubber product also contains a vulcanization system, which includes sulfur to vulcanize the rubber, accelerators for higher curing rate and activators (zinc oxide and stearic acid) to contribute the starting of curing process. The composition of the vulcanization system can be varied endlessly and determines both the properties of the vulcanized material and the characteristics of the crosslinking process.
- ***Ageing protectors (Antidegradants)*:** Antioxidants and antiozonants are used to protect the rubber product from oxidation and ozone cracking.
- ***Softeners:*** Mineral oils or ester plastisers are used to regulate the hardness and improve processing.
- ***Special ingredients*:** Some special ingredients such as pigments in light colour compounds, antistatic lubricants to reduce static electricity, blowing agents for sponge rubber or flame retarders to improve non-inflammability etc., can be used in manufacturing of different rubber products[6&8].

2.2 Manufacturing of Rubber Products

The manufacturing processes from raw material to rubber products can be divided into three different stages;

In the first stage, the raw materials are mixed together according to particular formulations and specifications (i.e. temperature, time etc.). Once the compounded rubber is blended through the mixing operations and formed into strip form or slabs, it is ready for the second stage of manufacturing to be processed into the desired product by extrusion, spreading, calendering or moulding. Brief descriptions of these processes are given in Appendix 2. Finishing operations are the following stage in the manufacturing of rubber products. Some of them could be cut, stamped or ground, where the others could be completed by being bonded to other materials like metals, plastics, glass fibres etc.

Once rubber products become ready for industrial and consumer purchases they are delivered through different distribution channels.

CHAPTER 3

IDENTIFICATION & COMPARISON OF DIFFERENT OPTIONS IN WASTE RUBBER MANAGEMENT IN SWEDEN

Once the rubber products have been used and reached the end of their service lives, they enter the scrap and recycling stream. In Sweden, approximately 60 000 tones of scrapped tires are generated every year[9]. Table 3.1 and Figure 3.1 show the 1998 values of different options that are carried on in scrap tire management. It is also estimated that, annually about 60 000 tones of industrial rubber products are manufactured[10], but there is no statistical data about the amount that reaches to the waste stream and their final fate.

Table 3.1 Management of used tires in 1998 in Sweden.

Different Options	Percent	
Reuse	**21%**	
Retreadable casings		8.5%
Misc. reuse/whole tires		12.5%
Material Recycling	**13%**	
Raw material recycling		6.5%
Civil engineering app.		6.5%
Energy Recovery	**46%**	
Cement industry		26%
Heating		20%
Export	**18%**	
Casings		10%
Shredded tires		8%
Disposal	**2%**	

Source: Svensk Däckåtervinning AB, March 1999.

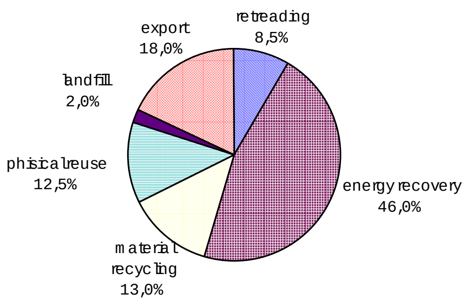


Figure 3.1 Rates of different used tire management options in Sweden (1998).

In the following sections of this chapter, alternative ways in the disposition and recycling of post consumer waste rubber are identified and analyzed.

3.1 Source Reduction

As in all kinds of waste management systems, source reduction/waste prevention is the most desirable alternative in waste rubber management. It is seen from the causal loop diagram presented in Section 5.2, that a reduction in *demand for new tires* and *demand for industrial rubber products*, will ultimately cause a decrease in the generation of *scrap tires* and *waste industrial rubber* together which represent the *total amount of waste rubber*.

Sections 3.1.1 and 3.1.2 analyze different ways to achieve a reduction in the amount of scrap tires and waste industrial rubber, respectively.

3.1.1 Reduction of Scrap Tires

Considering the future developments in dealing with the scrap tire problem, the main objective should be to reduce the amount of tires that enter the waste stream. In order to achieve such a reduction in the generation of scrap tires followings are some of the important measures that should be considered:

- ***Reducing the number of passenger cars***. A reduction in the number of passenger cars significantly causes a reduction in the demand for tires, which in turn reduce the amount of scrap tires. Using the model developed in Chapter 5, Scenario-2 illustrates how the demand for passenger car tires would reduce with a 10% reduction in the number of net increase of passenger cars that enter the traffic each year in Sweden;
- ***Increasing the life span of tires***. It is possible and easy to achieve an increase in the life span of tires simply by:
  - *Reducing the travelling distance*: With the public awareness in alternative forms of transportation or a reduction in the travelling distances the number of scrap tires could also be reduced. Scenario-3 in Chapter 5, shows the reduction in the number of scrap tires generated, with a 10% decrease in the travelling distance of passenger car tires in Sweden;
  - *R&D*: With more research and technological developments, the life span of tires could be increased. On the other hand, the major disadvantage of these new tires with longer life spans, is the difficulty of recycling mainly because of their complex chemistry;
  - *Improvements in tire and car maintenance*: Regular check for proper inflation pressure, rotation, correct balance and wheel alignment increases the life span of tires;
  - *Carefully driving*: Simply by avoiding making sudden starts and turns, high speed which wear tires out more quickly, and not driving into curbs etc., it is possible to extend the service life of tires.
- ***Increasing the use of retreaded tires***. The amount of scrap tires entering the waste stream could be reduced with the increased use of retreaded tires. More about this topic is discussed in detail in Section 3.2.1. Scenario-4 in Chapter 5 examines a possible increase in retreading rate in Sweden. With this scenario the expected situation of waste rubber management is tried to be illustrated with a retreading rate of 25%.

3.1.2 Reduction of Waste Industrial Rubber - "Conversion of Industrial Rubber Production to Thermoplastic Elastomers (TPEs) Production"

TPEs are defined as the materials that share many of the same properties of rubber. However, unlike conventional vulcanized rubber they can be processed and recycled like thermoplastic materials. Simply by being reground and melted, they can be recycled and remanufactured through moulding or extrusion processes due to their thermoplasticity[10].

Statistics and Application Areas
In the early 90's TPEs became an attractive substitute for rubber in certain products. Since 1970, the market for TPEs has been growing at an annual rate of 8%[12]. Today approximately 12% of total industrial rubber production is converted to TPE production in the global market and it is highly likely that this percentage should double by the early 21st century[1]. TPEs also account for about 15-20% of the non tire rubber products used in automotive industry[13].

Some of the specific applications for which TPEs have been replacing conventional vulcanized rubber products are given in Table 3.2. With the development of different types of TPEs such as more resistant to hot oil and higher temperatures, it is likely that there will be an increase in the number of products manufactured from TPEs[12].

Table 3.2 Application areas of Thermoplastic Elastomers (TPEs).

Application areas	Examples
For mechanical rubber products applications	caster wheels, convoluted bellows, flexible diaphragms, gaskets, seals, extruded profiles, tubing, mounts, bumpers, housings, glazing seals, valves, shields, suction cups, torque couplings, vibration isolators, plugs, connectors, caps, rollers, oil-well infection lines, handles, and grips.
For under-the-hood automotive applications	air conditioning hose cover, fuel-line hose cover, vacuum tubing, vacuum connectors, body plugs, seals, bushings, grommets, electrical components, convoluted bellows, steering gear boots, emission tubing, protective sleeves, shock isolators and air ducts.
For industrial hose applications	hydraulic (wire braid), agricultural spray, paint spray, plant air-water, industrial tubing and mine hose
For electrical applications	plugs, strain relief, wire and cable insulation and jacketing, bushings, enclosures, connectors and terminal ends.

Source: Coran A. Y. 1998. *Thermoplastic Elastomers: Science, History and Achievements*. Paris: IRC '98 Conference Proceedings.

Advantages and Disadvantages of TPEs over Conventional Vulcanized Rubber
TPEs have significant advantages over conventional vulcanized rubber. Compared to conventional rubber production, the overall processing operation is simpler for TPEs, which makes the product quality control easier and cheaper. There is no mixing and vulcanization processes within the production line of TPEs, therefore processing cycle times are shorter and the manufacturing rate is much faster. Also, total energy used in TPE product manufacturing is lower due to the shorter cycle times and the lack of vulcanization process. This provides economic benefits for the manufacturers. Additional to all, the major economical and environmental advantage of TPEs is that, waste generated during manufacturing can be reground and remanufactured with no significant loss in performance[12].

Besides it's advantages, there are few disadvantages of TPEs. Most importantly, they are relatively new materials and still need more research and development regarding their performance and capabilities. Due to lack of knowledge, many of the conventional vulcanized rubber products can not be manufactured from TPEs.

Thus, today recycling advantages of TPEs are only available for certain industrial rubber products (i.e it is not possible to use TPEs in tire manufacturing). An other problem that might be considered, is the initial capital investment which is needed for the new production lines when switching from manufacturing of conventional vulcanised rubber products to TPE products[12&14].

Role of TPEs in Automotive Recycling and (in connection) in Rubber Recycling
Industrial rubber products used in automotive industry continue to lose market share on a selective basis to TPEs[15]. This increase in the use of TPEs in automotive industry is mainly due to;

- design goals that aims to reduce the vehicle weight to decrease the fuel consumption;
- aesthetic changes with soft touch interiors;
- noise reduction;
- higher under-the-hood operating temperatures;
- an understanding of the design capability inherent with thermoplastic elastromers in systems design in combination with rigid thermoplastics;
- greater ease of recycling automotive rubber parts produced from TPEs as compared to conventional vulcanized rubber.

It is likely that there will be End of Life Vehicle (ELV) legislation in Europe[15]. Such legislation, which will be designed to aim a reduction in the quantity of vehicle shredded waste that goes to landfills, will increase the use of recyclable components in automotive industry. In this respect, the use of TPE products will continue to increase in automotive industry. Some of the automotive parts that will possibly be affected from such legislation and other reasons mentioned above and converted to TPEs are given in Table 3.3 in Appendix 3. Some of the big automotive companies especially in Germany have already started to ask their suppliers, to produce these rubber parts from TPEs[16].

It is also very much likely that, under the umbrella of Design For Environment (DFE) and Extended Producer Responsibility (EPR) concepts, the trend towards designing motor vehicles, household appliances and other assembled devices for easy disassembly and recycle will continue to accelerate with in the following years. Increasing pressure and in some cases governmental directions for marketers of these products to take them back at the end of their service lives will generate more incentive for the manufacturer to design it more environmentally friendly (i.e. increased use of TPEs in industrial rubber production rather than conventional rubber)[1].

Just as the automotive industry, similar pressure mainly due to environmental and economical considerations has started to come from other industries that use industrial rubber products in their productions. In Sweden, some of the industrial rubber manufacturers had already switched or are planning to switch to TPE production to respond their customers' requirements[16] (e.g. Nolato Gummi AB, National Gummi AB).

The amount of reduction in waste industrial rubber in Sweden simply by switching to TPE production is tried to be illustrated with Scenario-7 in Chapter 5.

3.2 Reuse

Reuse of old tires can be discussed under two headings, namely retreading and physical reuse.

3.2.1 Retreading

Retreading is the only end of life management option where the tires are reused for their original purpose. It is a perfect way of extending the product life and postponing the disposal problem meanwhile, reducing the amount of scrap tires entering to the waste stream. Tires can be retreaded either replacing only the tread section or replacing rubber over the whole outer surface. Since retreading extends the life of the tire by applying new rubber on a worn casing, it's viewed as reuse rather than recycling.

Retreaded tires are widely used by trucks, buses and airplanes mainly because of the large price difference between new and retreaded tires and also consumer satisfaction in overall performance. Passenger car tires can be retreaded once, truck tires 2 or 3 times where airplane tires up to 12 times[17].

In terms of energy and material recovery, there are considerable savings in retreading used tires. By retreading, the amount of oil saved from producing new tires is 21 liters per passenger car tire and 68 liters per truck tire and the amount of rubber saved is 4 kg and 44 kg respectively[18].

The retreading market represents a small part of the annual take-off and seems to be slow to expand in Sweden. Today, there are approximately 15 retreading facilities for passenger car tires and about the same amount for truck tires giving service[19]. Although retreading rate of commercial vehicle tires (i.e. lorry and bus tires) is high enough, with 15% retreading rate of passenger car tires, Sweden can not meet the European Union's target of 25%[20].

Among the other several factors, why retreading rate is small compared to other options in Sweden are;

- poor public image about retreading;
- design/manufacture of most passenger car tires without consideration of the need for retreading;
- ready availability of low cost and quality of tires which are unsuitable for retreading;
- loss of enforcement of the tread depth law;
- poor care of tires in use which disables retreading.

To overcome the barriers mentioned above, there is a need to;

- *increase the public awareness for using retreaded tires*: The poor image of retreaded tires should be dispelled by providing more information and people should be made sure about their safety.
- *set regulations for manufacturing of retreadable tires*: Certain types of tires could not be retreaded. By ensuring that all new tires are manufactured to be retreadable, the retreading rate could be increased.
- *encourage the purchase of retreaded tires*: In order to make retreaded tires more economically viable compared to cheap tires, passenger car tires should be exempted from recycling charge (as in the case of truck tires[19]), and/or have less taxation.
- *set regulations for minimum legal tread depth*: The condition of the used tire is very important for retreading. It is not possible to retread badly maintained and too worn tires. Enforcement with the legislation and regulations, could help to stop the use of illegal part worn tires. Also, the public awareness to the dangers of driving on illegal tires, which do not meet the official tread depth, should be increased.

3.2.2 Physical Reuse

Due to their easy availability, durability and low price, physical reuse of tires, sometimes with minor modifications, exist. Generally, artificial reefs in marine environment, applications in children playgrounds, boat and dock fenders in harbors usage, engineering applications in landfills, weights on silage sheeting on farms, motorway embankments, crash barriers at motor racing circuits, structural support for flood defense and applications in golf courses are some of the physical reuse of scrap tires.

Scrap tires have been reused for different purposes in Sweden. They are mostly reused in children playgrounds as swings and at motor racing circuits as crash barries[21].

3.3 Material Recycling

Material recycling of waste rubber, especially scrap tires, is one of the viable options to re-utilize the waste rubber as different means of resources after they reach to the waste stream.

3.3.1 Historical View of Rubber Recycling

Ironically waste rubber has been recycled since 1853[1]. With the generation of "reclaim" - a useful rubber compounding material - half of the rubber consumed at the beginning of the 20^{th} century was in the form of reclaim[21]. After World War II, a progressive decrease in the use of reclaim has generated mainly due to low virgin rubber prices and the trend to higher quality rubber products, specially radial tires. Environmental regulations imposing the reduction of pollution during the processing were other barriers for reclaiming industry during the last decades.

For many years the widespread use of recycled rubber as secondary raw material in manufacturing of new rubber products was held back by the strict quality requirements of rubber manufacturers and the enforcement of the environmental regulations. But the situation has slowly started to change within this decade.

Legislation encouraging recycling and restricting landfilling played an important role in this change. With the improved quality, the use of recycled rubber in manufacturing of rubber products has increased. Higher quality products can now be manufactured containing recycled rubber[22]. Today, significant reduction in raw material and waste disposal costs is the main incentive for the rubber manufacturers.

3.3.2 Recycling Techniques

Less than 5% of tires worldwide are now being recycled[23]. Although true recycling of vulcanized rubber products through devulcanization is technically possible, at present it is highly impractical for large-scale use mainly due to economical reasons. Some of different processes and methods used for material recycling of waste rubber are described and discussed below.

A) Shredding

Rubber waste is shredded mainly as a first step for the grinding process or for direct use in many different applications. Among the many other potential applications, one of the biggest one is to use them in civil engineering works. In civil engineering applications contrary to other recycling applications very large pieces of scrap tires in very large quantities are used. They are used specially as filling and lining materials in newly constructed roadbeds. Due to some of their specific properties presented in Table 3.4 in Appendix 3, they are also used in expansion joints, drainage systems, highway embankment and bridge abutments. Additional to these applications, with the recent noise reduction regulations the use of scrap tires in sound barriers along major highways and close to inhabited areas along passenger tracks represents a great potential in Sweden.

In the US, American Society for Testing and Materials (ASTM) prepared new guidelines, which set safe limits for the design and use of scrap tires in civil engineering works[24]. Similar guidelines in Sweden and EU, could be helpful to increase the use of shredded scrap tires in civil engineering applications in Sweden.

B) Grinding

Grinding process is generally required to separate the reinforcing textile or metals from rubber particles and prepare the granulated rubber to be used in either different applications (i.e. rubber compounds, rubberized asphalt etc.) or the next processing step of material recycling (i.e. reclaiming, surface activation)[25]. Due to easier processing requirements and higher quality materials, commercial vehicle (trucks, tractors, excavators etc.) tires are the majority of waste rubber processed in this way.

Different Types of Grinding Processes

There are mainly three types of processes that are differentiated from each other by the mechanisms that they produce granulated rubber;

- ***Mechanical Grinding:*** In this process rubber waste is shredded first and then fed into a grinding mill to be broken down into small pieces at ambient temperature. After grinding, steel and textile are separated from rubber granulate. The rubber granulate is then used in a broad range of end-products. It is common to produce 10-30 mesh ground particles with this process. Table 3.5 in Appendix 4 shows the relationship between mesh size and approximate particle sizes.

- ***Cryogenic Grinding*:** This process consists of cooling the shredded rubber to below the freezing point by using liquid nitrogen or compressed air, after which the frozen rubber can easily mechanically be crushed into small particles. Almost all fiber or steel can be separated from the ground rubber and this results a high amount of usable product and less loss of rubber. The particle size varies from 30 to 100 mesh with this process.

  Over the past 5 years, cryogenics has progressed in terms of using less liquid nitrogen and using compressed air alternative to liquid oxygen. These developments significantly reduce the overall production costs[26&27]. One of the technologies that uses compressed air substituted to liquid nitrogen called TCS-1 is presented in Appendix 5.

  Today, approximately, 35% of the cryogenically produced ground scrap rubber is reused in automotive industry for a wide range of products including tires, brake linings, cables and friction materials[26]. Also great portion is used in asphalt pavements.

  Operations in cryogenic grinding do not result in emission of any kind or the production of any significant amounts of solid waste, which would have to be disposed in landfills. In this respect, compared to other waste rubber management options cryogenically recycling of scrap tires should have a competitive advantage in Sweden where environmental protection concerns are strong. In Europe, in particular, where environmental protection philosophy is beginning to be a priority of the European Union, it is very likely that tire manufacturers may in the future be required to be responsible for the ultimate, post use-life disposal of their tires. For that reason, these tire manufacturers should be interested in supporting the development of such environmentally friendly rubber recycling systems.

  Currently, there is only one grinding facility in Sweden and it is cryogenic. Ground rubber processed in this facility is remanufactured in the same plant for different applications. (i.e. traffic stands, paving tiles, bumpers, target walls for shooting, flowerpots etc.)[28]

To make a comparison, profiles of the mechanical and cryogenic processes are adapted from European Tire Recycling Association (ETRA) and given in Table 3.6 and Table 3.7, respectively in Appendix 6.

- ***Chemical, Physical or Microbial Degradation*:** Some other different methods such that microwave, ultrasonic, chemical devulcanization and microbial degradation also have been used to produce ground rubber. One of the chemical devulcanization methods, called Ozone-Knife (OK) technology is discussed more in detail in Appendix 7.

Different Applications of Ground Rubber
Ground rubber can be used as a substitute for virgin rubber and is finding its way into new applications every day. Different sizes of ground rubber are used either as secondary raw material in re-manufacturing of different products or in various civil engineering applications as seen in Table 3.8.

Table 3.8 Various applications of ground rubber.

Different applications of ground rubber	
• compounding material in rubber industry for various applications	• additive to asphalt paving material (modification of bitumen with rubber)
• thermoplastic and rubber blends	• underlay for artificial sports turf
• component for friction material	• recreational surfaces
• solid tires	• flooring and surface for indoor and outdoor sports (playgrounds, tennis courts, soccer pitches, etc.)
• footwear	• water proofing compounds for roofs and walls
• irrigation pipes	• carpet underlay
• joint and crack sealant	• train and tram line beds and track guards
• bonding tape	• railway crossings

Ref.: (4, 17 & 26)

Rubberized asphalt, which could bring a solution for the waste rubber problem, is one of the major applications of ground rubber and is discussed more in detail below:

- ***Rubberized Asphalt and Potential Applications in Sweden***

The concept of adding granulated rubber, recovered from scrap tires, to asphalt has been experimented and tested for a long time. Today, in Canada and USA, currently the greatest demand for granulated rubber is to use it as an additive in asphalt for paving roads[17]. Most of the research and developments have showed that in almost all applications, rubberized asphalt makes roads safer and more durable. It has more advantages over conventional asphalt, when the weather conditions get tougher. It flexes in freeze and thaw conditions and resists damaging wear from tire chains on vehicles during winter months[29]. Some of the advantages of modified bitumen with rubber in asphalt paving applications are summarized in Table 3.9, below;

Table 3.9 Some advantages of rubberized asphalt.

Advantages of Rubberized Asphalt	
• longer life for the surface dressing	• the low temperature properties of the surface dressing are improved
• a reduction in pavement cracking and fatting up	• in many cases it is possible to achieve a reduction in the pavement thickness
• improved resistance to flow or deformation	• reduction the stopping distance
• improved adhesion and resistance to stripping	• reduction the winter salt requirement
• a reduction in aquaplaning (the water drainage capacity may be increased)	• reduction in road and driving noise

Ref.: (29, 30 & 31)

Although there were some arguments about the high construction costs of rubberized asphalt roads; their long term performance; environmental impacts that includes air emissions from the processes of rubberized asphalt plants; and the recyclability of the rubberized asphalt roads at the end of their service life[17], with the researches and developments all these arguments have been replied. The findings are:

- Roads constructed by using granulated rubber cost twice as much, but on the other hand last almost twice as long compared to conventional roads[4];
- According to asphalt rubber experts attended to “Rubber Recycling ’98: The North American Experience”, rubber modified asphalt works are no longer can be labeled a “new” technology. What they said was there is enough evidence now to demonstrate the product’s absolute value in lengthening pavement life, giving a smoother ride and dampening road noise[31];
- The emissions from the rubberized asphalt processing have so far indicated an environmental impact equal to normal asphalt applications[32];
- Contrary to popular belief rubberized road surfaces can be recycled[33].

According to Bureau de Liason des Industries du Caoutchouc (BLIC), the use of rubber in roads would be a very good idea, but it requires a political push and the political will does not exit in Europe[33]. So far, political and some technical aspects have limited the growth in rubberized asphalt applications[32]. To give an example, in the US, efforts for the use of ground rubber in road constructions were tired to be a national standard through legislation in 1991. But in 1995, with the pressure from individual states and from the bitumen suppliers (who would lose some of their market) led to the postponement of the measure and in 1995 the act was repealed[34].

Additional to regional road networks which require periodic repairs and resurfacing, during the following 4 years approximately 5000 km of new roads will be constructed in Sweden[35]. According to ETRA, in the construction of one kilometer of road surface, by using rubber-modified asphalt, 2500 scrap tires could be absorbed. In this respect, it is evident that the use of rubberized asphalt in Sweden is the look of the future. It does not only contribute to all advantages that are summarized above, but provide a major incentive to recycle potential environmentally damaging scrap tires.

C) Reclaiming

Replasticizing of scrap vulcanized rubber through a variety of processes, i.e. thermal, thermo-mechanical or some other chemical processes is called reclaiming [a]. In contrast to the thermal processes, the thermo-mechanical processes also apply a shearing force while reclaiming the waste rubber products. But in both processes heat and sometimes chemicals are used to plasticize the material[25].

Among many others, compounding materials, moulded products, automotive products (shock absorbers, battery housing, hoses, mats), bicycle and solid tires, conveyor belts, shoes, belts etc. are some of the applications that are produced by using different kinds of reclaimed rubber. Since there is no reclaiming facility in Sweden, rubber manufacturers import reclaimed rubber mainly from Holland and India, and use it up to a certain extent in some of their products such as tires[28&36]. This enables

[a] Further reading: Manuel H.J., Dierkes W., Recycling of Rubber, Rapra Review Report, No. 99, Volume 9, Number 3, 1997 (Different kinds of reclaiming methods are discussed more in detail)

them to have several advantages in processing (Table 3.10, Appendix 8) and reduce raw material costs.

Today, there are reclaiming industries, which work in co-operation with rubber manufacturers and supply their secondary raw material demand quickly, and with required standards and competitive prices[37] (i.e. Vredestein Rubber Resources in Holland). They receive the production waste from different manufacturers and after treating it, send back to be reused as a secondary raw material. Swedish rubber manufacturers should also work together with reclaiming industries, to have closed loop processes in terms of cleaner production.

As North American Rubber Recyclers' Association (NARRA) states[38]; "at this stage, the overall development in rubber reclamation industry is somewhat in the same position as the motor car was in 1910, but moving ahead at about 25 times the speed so that in three years it will be in the same position where the motor car is today in terms of modern technology applications for improved economics and product quality. Therefore, it is expected to have an enormous growth in this industry over the next four or five years and can be seen as the *window of opportunity*".

D) Surface Activation

An alternative to reclaiming is the surface activation of ground rubber. There are several different methods, which have been used to modify the surface or composition of granulated rubber to make it more compatible or useful. These methods can mainly be collected in three groups, namely, *activation by addition of chemicals, activation by gas treatment* and *mechanical or physical activation*[b] .

With the developments in reclaiming and surface activation, it is now feasible to incorporate post consumer recycled rubber in certain static automotive applications. Today, almost 75% of the natural rubber reclaim and surface activated ground rubber production supplies secondary raw material to automotive industry. Also an additional 5% can be reused in tire manufacturing[26]. In the US, with a development program sponsored by the Vehicle Recycling Partnership, treated[c] ground rubber is incorporated at levels of 25% in an automotive coolant hose compound and 37.5% in a brake cup compound[39].

3.3.3 Barriers to New/Expended Markets and How to Overcome

Among others, the main barrier to initiate manufacturing of new products by using recycled waste rubber is financial. Expensive research and developments in the area of different rubber recycling techniques, initial investment and operation costs of these recycling processes are the main obstacles to be overcome.

[b] Further reading; 1) Manuel H.J., Dierkes W., Recycling of Rubber, Rapra Review Report, No. 99, Volume 9, Number 3, 1997; 2) Dierkes W., Recycling-A Changing Scene, Tire Technology International,1998;(Different surface activation methods are discussed more in detail)

[c] The treated ground rubber used in this study was treated with Tirecycle, a proprietary surface treatment process by Goldsmith & Eggleton Inc.

As in the case of many other recycled materials, to build a demand for these new products and to extend the existing markets there are number of specific conditions to be satisfied;

First of all, waste rubber recycling must be logical and make good business. People who put effort on and invest in this industry must able to make good profit. Second, it must be based on reliable recycling method and technology, otherwise it does not make good business sense. And finally, it must be accepted both socially and politically. Swedish government should promote the development of rubber recycling industry and with effective marketing strategy, poor public image of recycled rubber products as inferior to ones made from virgin material should be overcame (See also Section 4.3.4).

3.4 Energy Recovery

Among countries in Scandinavia, the United States, Japan and Germany, due to significant economic and environmental reasons, energy recovery from used tires has been regarded as the best alternative in scrap tire problem. This significant interest in Tire Derived Fuel (TDF) has been mainly due to the manageable control of large amount of scrap tires in a practical, cost effective and timely manner.

There are two different processes in the literature, namely; *direct combustion* and *pyrolysis*.

3.4.1 Direct Combustion

Currently, the largest potentials for the use of scrap tires as an alternative fuel are cement manufacturing and electricity generation.

Cement Kilns
Scrap tires have a calorific value similar to coal and in some ways have advantages to coal[29]. This makes them an attractive form of fuel and thus can partially and directly can be replaced for coal in cement manufacturing. Use of scrap tires as a substitute for coal is not only an effective practice in waste rubber management, but it also reduces the use of non-renewable energy sources. Additionally, there are some other benefits gained in terms of product quality, since the steel reinforcement within the tire contributes to the strength of the final product.

Table 3.11 in Appendix 9 gives a profile of the energy recovery from scrap tires in a small sized cement plant with an average annual fuel consumption capacity of $\pm$20,000 tones scrap tires.

The use of scrap tires, as an alternative fuel in cement plants was a short-term panic reaction against their disposal problem. It has been seen one of the best practical, cost effective and timely manner solution for the problem. One draw back with this solution is that, after building or renovating cement kilns to use scrap tires as an alternative fuel, there is a need of ongoing supply of large volumes of tires to continue the production. As in the case of Sweden, the uptake of scrap tires within cement industry is relatively high and this limits the availability of scrap tires to the recycling industry and could block new developments in material recycling.

Besides, under the frame of sustainable development, and due to the commonly accepted hierarchy of all types of waste management alternatives (Reduce, Reuse, Recycle, Recover and then Disposal) much higher priority on material recycling of waste rubber should be placed than on energy recovery. If there is greater market opportunities in the recycling stream than is available at the cement kilns, then tires can find their ways to recycling industry.

In addition, with the proposed European regulations on emissions there will be a considerable pressure for cement kilns to comply with this emissions regulations[40]. This new change in emission standards could also push up costs regarding installation and proper maintenance of appropriate emission control devices. Considering these and the growing interest in recycling of waste rubber, there could be a decrease in the use of scrap tires in cement industry as an alternative fuel and an increase in material recycling in Sweden.

Power Plants
Scrap tires are used as fuel in electricity production to minimize the fuel costs. A profile of the energy recovery from scrap tires in a steam generation process with an average annual consumption capacity of ±20,000 tones scrap tires is given in Table 3.12 in Appendix 10. Currently there is no such an application in Sweden.

Other Industries
There are many examples of other industries that use scrap tires as an alternative fuel in worldwide. Metal works, paper mills and on a certain extent tire factories use tires as a fuel to obtain steam to be used within the processes. Similar to waste wood or paper, scrap tires are also an alternative fuel in lime production. An other application area is incinerators. Small quantities of scrap tires are mixed with household waste and burned in incinerators when the calorific value of the household waste is low. In Sweden some central district heating plants use scrap tires for this purpose[19].

There have been concerns about the toxic emissions from the combustion of scrap tires in cement plants, power plants, incinerators or any other industry. VOC's (i.e. benzene, chloroform, 1,2-dichloroethene, methylene chloride, and heavy metals (i.e. lead, mercury, chromium and zinc) are the most common concerned toxic emissions when tires are burned. Additionally, new chemical by-products called Products of Incomplete Combustion (PICs) (i.e. dioxins and furans) are created during the combustion. Pollution control devices can never work with 100% efficiency, no matter how new and improved they are, for the treatment of these toxic emissions. Besides, like any other equipment, they can break down over time, which could let the toxic emissions end up in the atmosphere.

3.4.2 Pyrolysis

Pyrolysis is the thermal degradation of a material with heat input in an oxygen free atmosphere. Gas, oil, carbon black and steel are the products from the pyrolysis of tires. Recovered gas and oil can be stored and used whenever needed, carbon black can be used in rubber and plastic production and the steel can be recycled. Although there are few pysolysis plants in UK and Canada, these processes are still mostly experimental, and have not yet proven themselves to be commercially viable[20]. There is currently no pyrolysis plant operating in Sweden. A profile of pyrolysis is given in Table 3.13 in Appendix 11.

3.5 Disposal

Due to the increasing concerns about conserving resources and energy, landfill is not a long-term solution in the scrap tire problem. With the proposed EU Directive, by the year 2003, ban for whole tire and three years later by 2006 for shredded tires will come into force[4]. The loss of material and energy content, the fire risk and the possible soil and water pollution are the major reasons for the landfill ban for scrap tires in EU. The progression of Landfill Directive about the disposal of scrap tires is given in Table 3.14 in Appendix 12.
Compared to other EU countries, Sweden has relatively low landfilling rate (2%)[41]. Therefore, it is safe to say that, such a ban will not have a big implication in the scrap tire management in Sweden. But in most of the other EU countries (i.e. in England where the landfilling rate is 26%), if other alternatives like retreading, material recycling and energy recovery are not supported and required measures are not taken, there will obviously be an increase in the illegal dumping of used tires.

3.6 Summary of Waste Rubber Management Options in Sweden

Considering the waste rubber management options - reduction, reuse, material recycling, energy recovery and disposal - there is a clear trend towards energy recovery in Sweden. Using scrap tires as alternative fuel reduces the amount of scrap tires, conserves natural resources, and enhances energy independence. In most cases it is the cost-effective solution. But it should be kept in mind that, there are many viable, higher uses for scrap tires that exist today and will evolve in the future (i.e. used as granulated rubber in rubberized asphalt paving, in rubber compounds for the manufacturing of different rubber products, and in various civil engineering applications etc.). Each of these applications should be developed, even if individually it does not have a major impact on the waste stream, together they will. Support must be given to existing material recycling technologies and as other solutions develop, they will be encouraged.

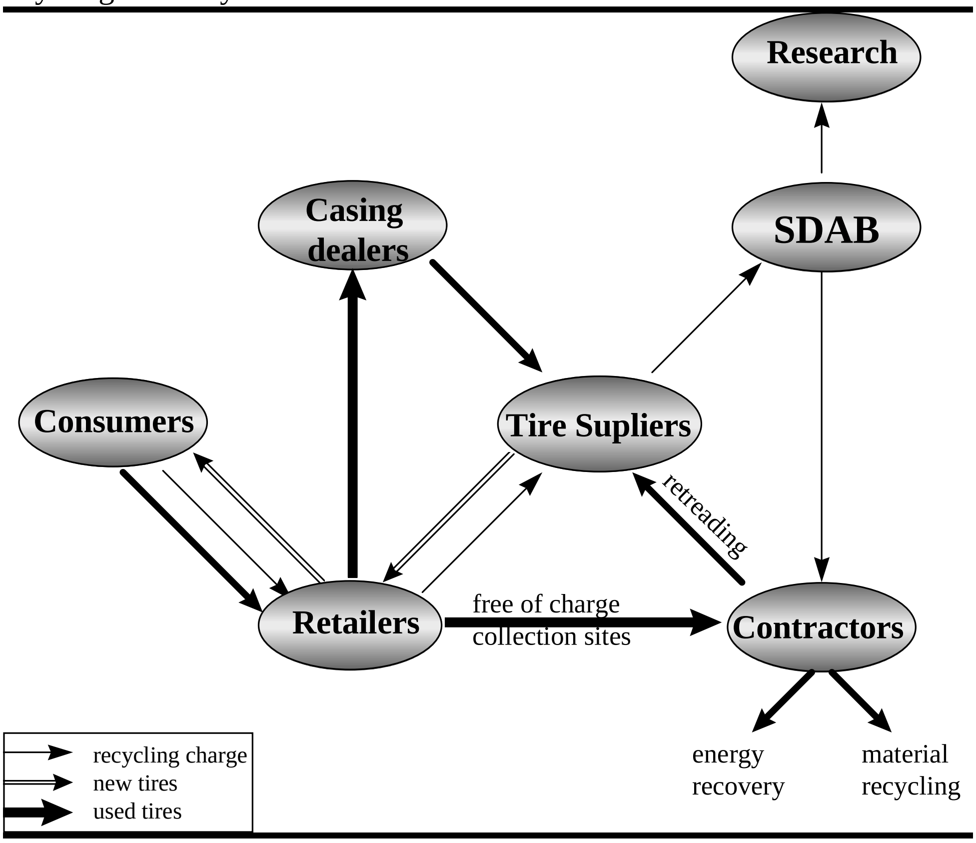
CHAPTER 4

REVIEW OF PRESENT SITUATION REGARDING THE FATE OF RUBBER AS WASTE IN SWEDEN

4.1 What is the Progress with Waste Rubber at the Moment in Sweden?

In 1994 the Swedish government selected the tire industry itself to manage the waste management of used tires on a voluntary basis. The collection system has been developed by the rubber industry and is run by a non-profit making organization called Svensk Däckåtervinning AB (SDAB). Currently, with more than a 90% collection rate, this system works quite well. SDAB is the responsible body for the overall supervision of the system, which is financed by fees that are charged for every new tire sold. To fund scrap tire management and disposal efforts, consumers are charged by the retailers who are in turn charged by the manufacturers (Figure 4.1). Today this charge is SEK 7 for passenger car tires, SEK 68 for truck tires and SEK 300 (all excluding VAT) for construction and other heavy machinery tires[41].

Figure 4.1 Material and money flow in the collection, sorting and recycling/recovery of tires in Sweden.



Source: Svensk Däckåtervinning AB

4.2 Relevant Legislation and Regulations

With the ordinance (1994:1236) came into force on 30 September 1994 (Appendix 13), the Swedish government legislated producers' responsibility for tires. This ordinance regulates the disposal of scrap tires in an environmentally acceptable manner and aims that 60% of the scrap tires generated shall not be landfilled after 31 December 1996, and 80% after 31 December 1998. Today with more than 90% collection rate this objective has highly achieved.

Scrap tires were also identified as a 'priority waste stream' by the European Commission (EC) in 1991, and the need to draft legislation or codes of practice to deal with scrap tire problem has been recognized. In 1993, the EC Working Group on priority waste streams produced a final draft Commission Recommendation on used tires[4&22]. With this Recommendation measures on prevention, collection, retreading, recovery and disposal are proposed, and the following targets were set to be met by the year 2000;

- abandon the disposal of used tires to landfill or incineration without energy recovery;
- prevent the generation of used tires in order to limit the increase in the year 2000 to less that 2% of the tires generated in 1990;
- achieve the retreading of a minimum of 25% of first life scrap tires;
- recover the materials and/or energy from 65% of scrap tires;
- avoid the other 10% of the problem by making tires last longer;
- achieve the recovery other than through retreading of a minimum of 5% of first life scrap tires.

With this Recommendation and a Code of Practice the aim was to increase the support for the development of alternatives to landfill in the management of scrap tires. The EC has yet to announce whether it accepts the EC Working Group's proposal as a recommendation, which would have no statutory force, or whether it prefers to introduce another measure[20].

As it was mentioned in Section 3.5 there is a proposed European Commission Directive that will possibly ban the landfilling of whole tires from about 2003 and shredded tires from 2006. Currently, large quantities of used tires are being sent to landfills in most of the European countries. If nothing is done to promote the other options (i.e. material recycling and energy recovery), there is a risk that the number of uncontrolled and illegal disposal of scrap tires will increase. Compared to other European countries, with a rate of only 2%, in Sweden small volumes of scrap tires are disposed at landfills and it is likely that this possible ban will not create a problem in Sweden.

With new EU emission regulations lower emission limit values are set regarding the incineration of waste. These regulations could highly influence the management of used tires in Sweden. To comply with these regulations, especially cement manufacturers have started to be concerned about the increased maintenance and operation costs of their treatment units. Sweden, with a high-energy recovery rate of 46%, has a well-established energy recovery system, which has been able to process a large portion of the total used tires. If a possible decrease occurs in the use of scrap tires as alternative fuels especially in cement plants, there could be significant changes in waste rubber management towards material recycling in Sweden.

One point, that might shape the management of waste rubber in Sweden, is a possible EU ecolabelling scheme for tires (currently, a proposal is being considered)[4]. This ecolabelling scheme would provide customers with relevant information to determine their purchasing decisions. The consumers could look and ask for different criteria regarding safety, durability, retreadability, noise generation and energy consumption of the tires. The growing public awareness and this possible EU ecolabelling scheme could influence the market in future resulting big changes in the management of waste rubber. There are also plans for European regulations on retreading to raise the standard throughout Europe[4], which also could increase the retreading rate in waste rubber management practices.

An other important point is the possible end of life vehicle legislation in Europe. With this legislation the use of recycled rubber material containing interior components and more recyclable TPE products in different applications in automotive industry will probably increase.

4.3 Major Stakeholders in Swedish Rubber Industry and their Roles in Rubber Recycling and Recovery

Shaping a sustainable rubber industry in Sweden requires the involvement, active participation and co-operation of different actors. Some of the major stakeholders of the Swedish rubber industry, which may play important role in the future progresses (i.e. possible opportunities and threats) of the sector, include the followings;

4.3.1 Automotive Industry

Automotive industry, the major source of post consumer rubber products, has been influencing the growth of the rubber industry. In addition to tires, many different types of industrial rubber products are utilized by this industry.(e.g. hoses, belts, gaskets, weather stripping, glass encapsulation, air dams and deflectors, and door, window and closure seals etc.).

Today the amount of rubber used in tires represents approximately 60% of the total rubber consumption in the world[9]. About 25% of the remaining 40% of industrial rubber production is also utilized by automotive industry[42].

Since, the automotive industry is the most dominant market for rubber products, specially with the possible End of Life Vehicle legislation, the impact of this industry on rubber industry would be significant (see Section 3.1.1). There is an ongoing and unclear problem in automotive recycling industry regarding the recovery of value from the rubber used in vehicles. The proper reuse of this rubber material is a major challenge for today's technologists and entrepreneurs. However, because the automotive industry aims to use recycled post consumer rubber in every application, where it makes sense on the basis of performance and economics, product engineers from automotive industry should co-operate with the rubber industry to be aware of the choices that they have available or/and can be improved. With this co-operation in a market driven economic system, a continuous improvement in both automotive and rubber recycling industries could be achieved.

4.3.2 Consumers

The rise of environmental thinking in large consumer groups has created a market where recyclability, ecolabelling and sustainable production policies are all important aspects of consideration. The willingness to pay for more expensive products is in part related to information about the processes in which cleaner technologies are used to provide the customers with environmentally friendly products. In that sense, new rubber products manufactured from recycled waste rubber could make good business.

Swedish rubber industry should prepare itself to manufacture high quality recycled rubber products with improved technologies/methods and market them with good marketing strategies. In the near future, consumers with improved environmental awareness would probably start to ask for and buy retreaded/retreadable tires or look out for products manufactured from waste rubber such as porous hose pipes, carpet underlay etc. Just as, surveys carried out by Michelin North America Inc., on consumers' willingness to accept recycled content tires, showed that about 60% of consumers are interested in a recycled tire and 25 % of those said they are very interested[43].

4.3.3 Rubber Recycling Industry

As it is seen from the Figure 4.1, SDAB is the only responsible body for the overall supervision of the scrap tire recycling system in Sweden.

After the tires collected at different collection stations throughout the country, they are classified and the ones in relatively good condition are either sent to be retreaded or exported to other countries in which the demand on the quality of the tires is lower. Ragn-Sells AB, the general contractor for the **collection**, **handling** and **sorting** of tires, takes care of these processes.

The remaining tires are then sent to **processors**. It is possible to analyze the processors under three different subtitles; *shredded rubber processors*, *ground rubber processors* and *integrated firms*.

In Sweden, the main markets for shredded scrap tires are cement plants that use TDF as a substitute fuel and up to a certain extent civil engineering applications. There are two immobile and two mobile shredders, which supply the shredded scrap tires for these markets.

Ground rubber processors reduce shredded tire scrap's size further and remove all the non-rubber components. With the increasing research and development in the use of granulated rubber in recycled rubber content products and applications, the future for granulated rubber processors seems to be positive. Currently there is only one ground rubber processor in Sweden.

Integrated processors, who produce granulated rubber and then use it by their own to make recycled rubber products, will probably show a great growth when it is realized that the best opportunity to make profit is in product manufacturing. The only grinding facility in Sweden, Gotthard Returdäck AB, processes the scrap tires and manufactures various finished products. Yearly 3000 tones (where the actual capacity is 20 000 tones/year) of ground rubber is processed in this facility[28].

In today's rubber recycling industry, the most important and powerful, but on the other side the least developed stakeholders are the **End-Users**. Increased use of recycled rubber materials in existing applications and further developments of new applications are the key factors in the management of waste rubber. The major players in the end-use sector are;

- Tire manufacturers
- Transportation agencies
- TDF users (cement industry-paper industry-power generators)
- Industrial rubber manufacturers (i.e. mats, solid wheels, friction breaks and other industrial, agricultural and automotive rubber products.)

Improved end-use applications with concerned government and public action can lead to increased recycling of waste rubber. The bigger the market capacity, the higher will be the processing volumes. If such a trend can be caught, then the rubber recycling industry will put all their efforts, technologies and financial resources to create the best possible end results for the material. Technology, high quality, effective marketing and acceptable cost are the challenges that end-users must meet to produce recycled content rubber products.

It should be on the agenda of SDAB to allocate money coming from disposal fees towards recycling rather than energy recovery. If Sweden's energy recovery rate from scrap tires are compared to EU waste management targets for year 2002 set out in 1991 (Table 4.1), and the overall European tyre waste management statistics for year 1996-1997 (Table 4.2), it is seen that, the energy recovery rate in Sweden is almost three times bigger than these values. It will be interesting to see if SDAB works in co-operation with government and other related bodies, and concentrates on material recycling practices in waste rubber management which is far from the EU waste management goal of 50%.

By being well informed in its sector, SDAB should provide a forum between collectors, processors and end-users to discuss opportunities for future recycling business enterprises and inform them with the latest technical and political developments in the industry. Co-operating with these bodies, it should also study and release annual reports on the state of waste rubber management, which could be useful for Governments future policy decisions on this hot topic.

SDAB should initiate programs that provide a purchase price advantage to tires sold within the country that contain a percentage of recycled (recovered rubber) tire material. As an example, all tires containing recovered rubber could be exempted from the disposal fee, as is currently the case for retread truck tires.

Working together with Swedish Rubber Manufacturers Association (SRMA), Government and Media etc., SDAB should also try to raise public awareness about the range of products that are manufactured with/from post consumer recycled rubber content (e.g. by collecting all these products in a catalogue). This has significant potential to extend the market for these recycled content products and hence the development of Swedish rubber recycling industry.

Table 4.1 EU Waste Management targets.

EU Waste Management Targets for year 2002	
Reduction	10%
Reuse	25%
Recycling	50%
Energy Recovery	15%
Landfill	0

*Source:*http://www.catalog.com/tec/wlibrary/rubb98.html

Table 4.2 EU Tire treatment patterns.

EU Tire Treatment Patterns 1996-1997	
Part-worn	11%
Retreading	10%
Civil Engineering	6%
Size Reduction	6%
Energy Recovery	14%
Landfill or other	52%
Unknown	1%
Total	**100%**

Source: European Tire Recycling Association

4.3.4 Swedish Government

New EU emission regulations were set regarding the incineration of waste, and changes in environmental legislation leading to a ban for landfilling of scrap tires is on the way. These progresses with the possible ecolabelling scheme for tires, regulations for the manufacturing of retreadable tires and legislation for end of vehicle life could influence the rubber industry considerably. In this changing environment to support the Swedish rubber industry, Government should:

- start up source reduction programs in co-operation with SRMA, SDAB and media to encourage Swedish drivers to reduce their travelling distance and use retreaded tires.
- set an example by participating in research and development programs on recycling of waste rubber;
- perform specific testing on recycled content rubber products (i.e. the reliability of rubberized asphalt on highways could be checked; the value and performance of using retreaded tires could be measured);
- intend to contribute to make *the use of rubberized asphalt* and *civil engineering applications* practical, economic and environmentally friendly practice throughout Sweden;
- evaluate and promote the potential market for the products manufactured from recycled waste rubber (i.e. railroad crossings);
- lead the way in education programs that help to eliminate misconceptions about recycled rubber products being inferior to virgin products as in the case of any other recycled product.

4.3.5 Swedish Rubber Manufacturers' Association (SRMA)

SRMA's one of the major missions should be to ensure the long-term viability of waste rubber management through Sweden. By considering the economic and environmental benefits, SRMA's goals should be:

- to promote the reuse, recycle and recovery of waste rubber
- to promote and assist the rubber recycling industries in legislative, judicial, and regulatory arenas in co-operation with SDAB;

- to increase the market share of recycled rubber content products and applications;
- to ensure that decision makers, the general public, and the media understand the contribution of the rubber recycling industry to the environment.

4.3.6 Institutions, Universities and R&D Centers

Through education and research waste rubber management options have been improved. Today, an important task for scientific institutions, universities and other research & development centers is to supply the latest technologies and information in waste management practices and to raise the environmental awareness of Swedish rubber industry.

In this respect, to increase the life span of tires and to improve the performance and capabilities of TPEs are two major challenges for these scientific institutions. To do so, it is significantly important for these institutions to collaborate with the rubber and automotive industries to achieve better results.

An other important task for these educational institutions is also provide information to Swedish rubber industry regarding new measures in their manufacturing processes such as waste minimization procedures and cleaner production practices.

4.3.7 Swedish National Road Administration's (SNRA)

As extracted from SNRA's Environmental Report 1998, "SNRA's environmental policy forms the basis for the development of the road transport, with a view to achieving an acceptable impact on the climate, sustainable energy supply, tenable emissions of pollutants, *acceptable noise levels*, *sustainable management of natural resources* and an infrastructure which takes into account the natural and cultural environment."

In this respect, SNRA sets environmental goals for the state road network, which covers the reduction in noise levels[d] , winter salt consumption[e] , road wear[f] and the use of non-renewable natural resources[g] . SNRA also states to use environmentally friendly methods in road management and co-operate with the public, the business sector and other authorities and organizations with a view to employing their expertise, commitment and willingness to take on responsibility.

Summing all above SNRA's statements and projections in road construction, there is a big potential for the use recycled rubber in rubberized asphalt pavements and civil engineering applications, which could influence the Swedish rubber & rubber recycling industries significantly.

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[d] The following guidelines should not normally be exceeded after the construction of new roads or substantial reconstruction work on the road traffic infrastructure:

- 30 dB(A) equivalent level indoors
- 45 dB(A) maximum level indoors at night
- 55 dB(A) equivalent level on exterior wall
- 70 dB(A) maximum level in outdoor areas close to housing

the first area where action should be taken covers existing residential environments where equivalent outdoor noise levels equal or exceed 65 dB(A). Measures should lead to reducing indoor noise levels, which exceed the guidelines for acceptable levels. The interim goal should be achieved by 2007 at the latest, but no longer than 2003 for the state road network.

[e] Salt consumption should not exceed 200,000 tones/year by the year 2000.

[f] Road wear should not exceed 130,000 tones/year by the year 2000.

[g] 90% of all new road surfacing in the year 2000 should be made from recycled material.

4.3.8 Media

The media is an other important stakeholder due to its capacity to reach the public in a fast and efficient way. It is important especially for tire and automotive industry to make use of the media in promoting and informing the public about environmentally sound recyclable, reused or recycled products (i.e. TPE applications, retreaded tires and recycled rubber content products).

4.3.9 Competitors

The main influence from competitors is competition for market shares by improving recycled rubber content product quality and the preferable alternative industrial rubber products manufactured from TPEs. At this point benchmarking, an important tool in product/process improvement comes into consideration.

CHAPTER 5

MODELLING AND SCENARIO ANALYSIS

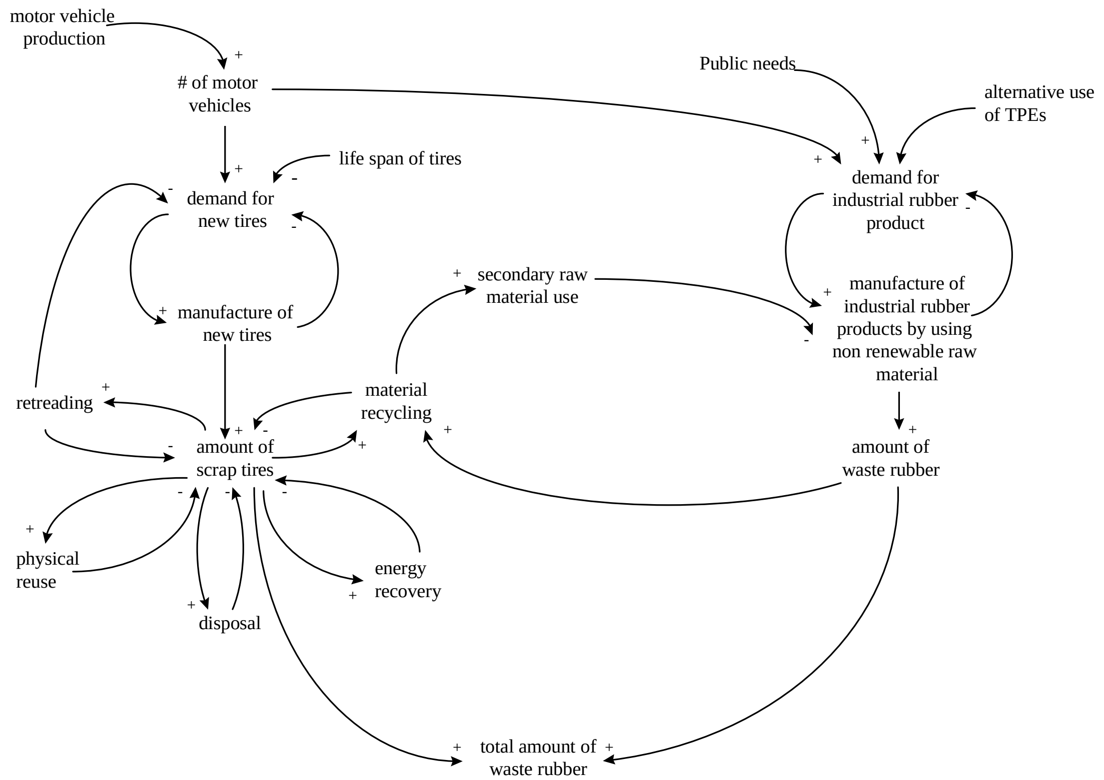
5.1 Introduction

To understand and evaluate the options for achieving a sustainable waste rubber management system in Sweden, the causal loop approach is used in this thesis. Based on the concept of system dynamics, the links between different issues, possible problems arising from them and the solutions, and their relation to sustainable waste rubber management system are analyzed by understanding the cause and effect relationship between important parameters.

5.2 Causal Loop Diagram

Following Figure 5.1 presents the schematic design of system dynamics in causal loops diagram.

Figure 5.1 Causal loops diagram of waste rubber management system



Two main issues and related problems are addressed in the diagram;

- Demand for tires

The pressure for motor vehicle production leads to an increase in the number of vehicles in use, which also cause an increase in the demand for tires. This leads to an increase in manufacturing of new tires. The more the new tires are manufactured, the more will be the amount of scrap tires that enter to the waste stream after their use.

The increase in the amount of scrap tires, will ultimately cause an increase in the different options of dealing with the scrap tire problem, namely; source reduction, reuse (retreading and physical reuse), material recycling, energy recovery, export and disposal.

As it is seen from the causal loop diagram, a reduction in the motor vehicle production and an increase in the life span of tires are two of the different ways of source reduction that directly decrease the demand for new tires and cause a decrease in the generation of scrap tires. Retreading on the other hand, is an other option to decrease the demand for new tires while at the same time, reduce the amount of scrap tires that enters to the waste stream. Additionally, increased material recycling of waste rubber (especially tires) allows the use of secondary raw material in re-manufacturing of new products.

- Demand for industrial rubber products

Besides the public needs that generate a demand for industrial rubber products, the pressure for motor vehicle production which leads to an increase in the number of vehicles, is the main reason in the increase of demand for industrial rubber products. This increase, causing also an increase in the manufacturing, finally leads to an increase in the amount of waste industrial rubber.

It is clear to see from the causal loop diagram that with a reduction in the motor vehicle production and increased use of TPEs, the amount of waste industrial rubber can be decreased.

5.3 Description of the Model

The reason to develop this model is to help the decision-makers to evaluate different scenarios in waste rubber management. It is developed by using software called Stella 5.1.1u, and can be analyzed under three different parts with nine sectors (See the map of the model in Appendix 14) as follows;

- **PART I - Vehicle Tires**
  - Sector I - Passenger Cars (PCs)
  - Sector II - Passenger Car Tires (PCTs)
  - Sector III - Lorries (Ls)
  - Sector IV - Lorry Tires (LTs)
  - Sector V - Buss Tires (BTs)
  - Sector VI - Other Vehicle Tires (OVTs)
  - Sector VII - Total Scrap Tires (TSTs)

- **PART II - Industrial Rubber Products**
  - Sector VIII - Industrial Rubber Products

- **PART III - Total Waste Rubber**
  - Sector IX - Total Waste Rubber

5.3.1 Tires

In this part of the model, calculations mainly regarding the *amount of vehicles,* their *tire demand* and the *amount of scrap tires they generate* are made within different sectors. These sectors are described more in detail below.

Sectors I & II-"Passenger Cars (PCs)" & "Passenger Car Tires (PCTs)"
Sector PCs introduce the net increase in the amount of passenger cars in Sweden. There are several different factors (i.e. demographic, socio-demographic, geographic) that can influence and determine this increase and they lie out of the scope of this study. Therefore forecasts obtained from official published data and projections are used in this sector. To determine the *net increase in the number of PCs,* forecasts for population increase[3] and for the number of PCs in use per inhabitant[2] are used in the calculations.

In sector PCTs, the *tire demand from PCs* (both new and retreaded tires), *number of PCTs in use* and *the number of scrap PCTs* that enter the waste stream are calculated. Main calculations and the assumptions/estimations used during these computations are as follows;

- Almost all of the PCs are equipped with five tires; four on wheels and one spare and it is unlikely that this situation will change in the foreseeable future[44]. However use of so called "safety" or "run flat" tires and light spare tires compared to the other tires, have reduced the average number of tires used in a PC. On the basis of informed guesses based on discussions with industry representatives it was published[44] that today average number of tires in a PC is 4.7. However the situation in Sweden is a bit different from many other countries. 80% of the PCs in the country have an additional pair of winter tires due to the climatic conditions[45]. Therefore in the model it is estimated that a PC in Sweden has an average of 6.3 tires.

- To calculate the new tire demand from PCs, first the average number of tires in a PC and the net increase in the number of PCs are multiplied to find the new tire demand from only new PCs. Then, to calculate the demand from existing old PCs, the demand for retreaded PCTs is subtracted from the number of scrap PCTs.

- Due to 1998 figures, 8.5% of the total scrap tires are retreaded, almost all of which represent the PCTs since retreadable lorry or bus tires don't enter the collection system. These retreaded tires meet only half of the market demand in Sweden and the remaining half is imported from other countries[19]. So, the addition of the number of retreaded PCTs calculated in sector IX and the number of imported retreaded PCTs correspond to the demand for retreaded tires from PCs.

- Among many others, type of the tire, driving distance, road and traffic conditions, driving style and weight loaded on the vehicle are some of the factors that determine the life span of a tire. Due to lack of knowledge on the actual influence of different factors and availability of data these factors are not taken into consideration. To make it reliable, estimates that are discussed with the representatives form tire industry are used in the model. It is assumed that average driving distance of a PCT is 50 000 km, and it travels 10 000 km per year. Hence, the average life span of a PCT is calculated 5 years.

- In order to calculate the total weight of scrap PCTs (in tones) that enters to the waste stream, the average weight of a PCT is need to be known. It is difficult to estimate the exact average weight of a PC simply due to different types of tires, therefore using figures obtained from ETRA (which says it's $\pm$ 6.5-7.5 kg), it is assumed to be and used 7 kg for the average weight of a PCT in the model.

Sectors III & IV - "Lorries (Ls)" & "Lorry Tires (LTs)"

Unfortunately there is no forecasting studies regarding the number of lorries in Sweden. For this reason, in Sector Ls the number of lorries is assumed to be increase by 3000 per year for the following twenty years.

After introducing the yearly net increase in the number of lorries in Sector Ls, *the tire demand from Ls* (both new and retreaded tires), *number of LTs in use* and *the number of scrap LTs* which enter the waste stream are then calculated in Sector LTs. Some of the major calculations and the assumptions and estimations used in these calculations are;

- It is very difficult to estimate the average number of tires that a lorry has, mainly due to the various sizes and types of lorries. To get more accurate results, it is much better to divide lorries into different subgroups (i.e. light utility lorries, heavy goods lorries and long haul lorries) according to their sizes and types and then make estimations regarding the average number of tires used in those. But due to lack of available statistical data, the average number of tires in a lorry is assumed to be 10 relying on the interviews with experts and several publications.

- It is estimated that 70% of the lorry tires are retreaded in Sweden[9]. Therefore, net increase in the number of lorries multiplied with the average number of tires they have plus 30% of the scrap LTs represents the new tire demand from lorries.

- The same procedure used in sectors PCs and PCTs is followed in these sectors (Ls and LTs) to calculate the amount lorry tires in use, life span of a lorry tire and the total wieght of scrap lorry tires generated. To be used in the computations, based on different sources and the interviews with experts, it is estimated that a lorry tire as an average weighs 50 kg[40], has driving distance of 110 000 km[44], and travels 20 000 km per year.

Sectors V - "Bus Tires (BTs)"

For the last ten years, there has been no significant change in the number of busses in Sweden. Today there are approximately 15 000 busses in use[3] and it is assumed that there will not be a substantial increase in this amount. Therefore, *the tire demand from Bs*, calculated in sector Bs, will not increase as in the case of passenger cars or lorries. Again, the same procedures used in the sectors PCs & PCTs and Ls & LTs are used in these two sectors to calculate the tire demand from busses (both new and retreaded tires), number of BTs in use, life span of a BT, the number of scrap BTs and the total weight of scrap BTs.

The assumptions and estimations made in the calculation of these parameters are as follows; the average number of tires in a bus is assumed to be 8, and it is estimated that a bus tire as an average weighs 20 kg, has driving distance of 110 000 km, and travels 20 000 km per year. It is also estimated that 70% of the bus tires are retreaded in Sweden.

Sector VI - "Other Vehicles Tires (OVTs)"
Similar to busses, for the last ten years there has been no significant changes in the number of agricultural vehicles (tractors), caravans and motorcycles in Sweden. Today there are approximately 325 000 tractors, 200 000 caravans and 130 000 motorcycles in use in Sweden[3]. And it is estimated that there will not be a significant increase in these amounts. It is also assumed and estimated that;

- tractors including their trailers have an average of 8 tires. Two of them are large tires with an average weight of 100 kg and the rest 6 tires are small sized which weighs 7 kg
- caravans have 4 tires each of which weighs 7 kg
- motorcycle tires weigh 5 kg each.

Sector VII - "Total Scrap Tires (TSTs)"
In this sector, first the total amount of scrap tires generated and then the amount collected are calculated. It is assumed that the collection rate is 90% and will not change in the future. Following this, the amounts of reused (retreaded PCTs and phsysically reused), recycled, recovered, exported and disposed scrap tires are calculated for the following twenty years in Sweden.

5.3.2 Industrial Rubber Products

Due to the lack of availability of information about the yearly production of thousands of different types of industrial rubber products, a basic and simple sector called "Industrial Rubber Products" (IRPs) is constructed within the model. This part of the model gives an idea of the general situation in industrial rubber production section of the rubber industry in Sweden.

Sector VIII - "Industrial Rubber Products (IRPs)"
Sector VIII makes calculations regarding the use of TPEs and recycled waste rubber in manufacturing of various industrial rubber products (i.e. decrease in the amount of rubber used in industrial rubber products with increased use of TPEs and recycled secondary raw materials). Consulting to the experts, it is estimated that the yearly industrial rubber production is approximately 60 000 tonnes[10] and currently about 12% is assumed to be manufactured from TPEs[1]. It is also assumed that every year 60 000 tonnes of waste industrial rubber is generated.

5.3.3 Total Waste Rubber

Sector IX - "Total Waste Rubber (TWR)"
Amount of scrap tires and *waste industrial rubber* which are calculated in the first two parts (Part I & Part II) of the model are used in this part of the model. By using these values, Sector IX in Part III finally computes the total amount of waste rubber generated in Sweden.

5.4 Scenario Analysis - Results

The aim of developing this model is to provide a better understanding of the impact of alternative decisions and/or different progresses on Swedish waste rubber management system. Seven scenarios are simulated with the model developed and each of them considers different possible aspects that might affect the future structure of the waste rubber management. Although it is highly possible to expect more than one scenario to occur at the same time, in the following sections each scenario is presented and examined individually. However, it is possible to run the model with different combinations of scenarios. It is also possible to expand the scope of the model simply by including more variables to answer more "what if" questions. Following are the scenarios presented in this thesis:

- Scenario-1 : No change in the current management practices;
- Scenario-2 : 10% reduction in the number of passenger cars that enter the traffic each year;
- Scenario-3 : 10% reduction in the travelling distance of passenger car tires (which also represents a 10% increase in the life span of passenger car tires);
- Scenario-4 : 30% retreading rate in passenger car tires;
- Scenario-5 : 25% material recycling of total scrap tires;
- Scenario-6 : 0% disposal of scrap tires in landfills by year 2003;
- Scenario-7 : Replacement of 25% of industrial rubber production by TPE production.

Following sections describe the scenarios more in detail and give the results in graphical form obtained from different simulations. Results are also compared to Scenario-1's, which illustrates the future situation of waste rubber management with no significant changes in the current practices.

5.4.1 Scenario-1

Scenario-1 aims to answer the question "How will the future structure of waste rubber management be during the next 20 years in Sweden, if the current practices are maintained without any substantial changes?". With all data, forecasts, estimates and assumptions used in the model, the amounts of *total scrap tires*, *waste industrial rubber* and *total waste rubber*, that are expected to be generated during the next 20 years in Sweden are presented in Figure 5.2.

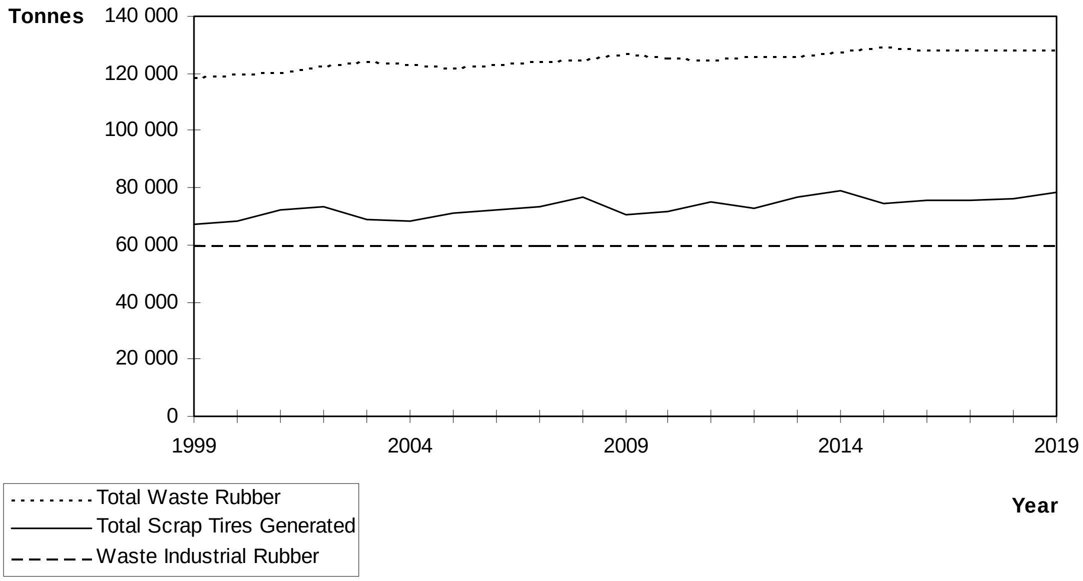


Figure 5.2 Results obtained from the simulation of Scenario-1 show that by year the 2019 the amount of total scrap tires generated in Sweden increases by 16.3% and reaches an amount of 78.4 thousand tones which is about 11 thousand tones more than today's value. This increase also reflects to the amount of total waste rubber.

Today, 8.5% of total scrap tires collected in Sweden are retreaded, where 12.5% is physically reused, 13% is recycled for material recovery, 18% is exported, 46% is used for energy recovery and 2% is disposed. Unfortunately, there are no significant waste management practices for waste industrial rubber products mainly due to difficulties in collection and sorting. Figure 5.3 shows the amount of scrap tires that are expected to be handled by different management options in Scenario-1.

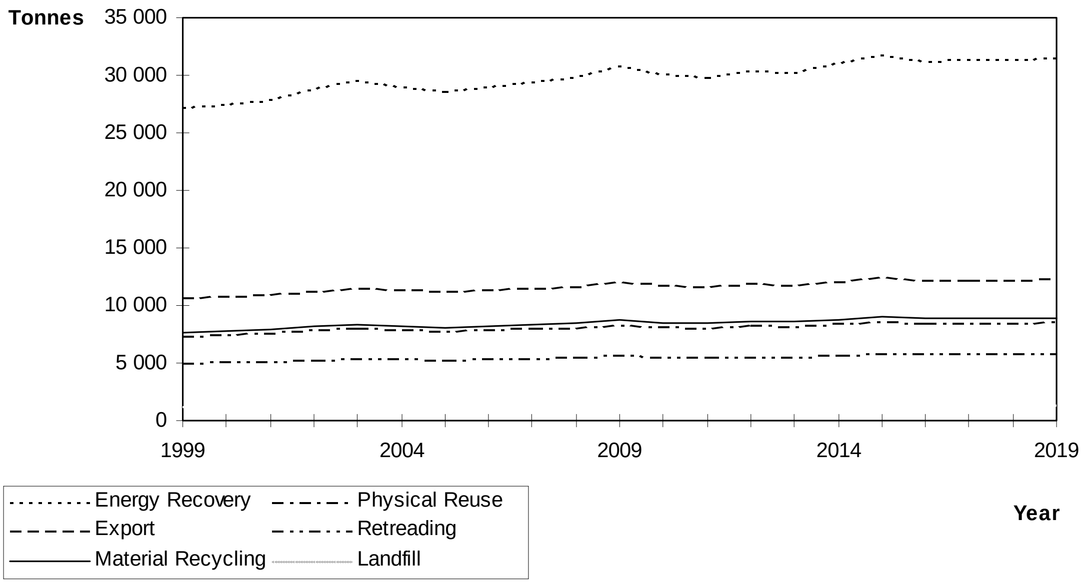


Figure 5.3 With the increasing number of scrap tires, the amounts that have been managed by alternative ways are also expected to increase during the next 20 years period.

5.4.2 Scenario-2

In Scenario-2, the model is run with the same conditions as in Scenario-1, except for a 10% reduction in the number of net increase of new passenger cars that enter the traffic every year. The less the increase in the number of passenger cars, the less will be the demand for tires. Figure 5.4 shows the effect of this reduction on scrap tire generation and the total amount of waste rubber generated.

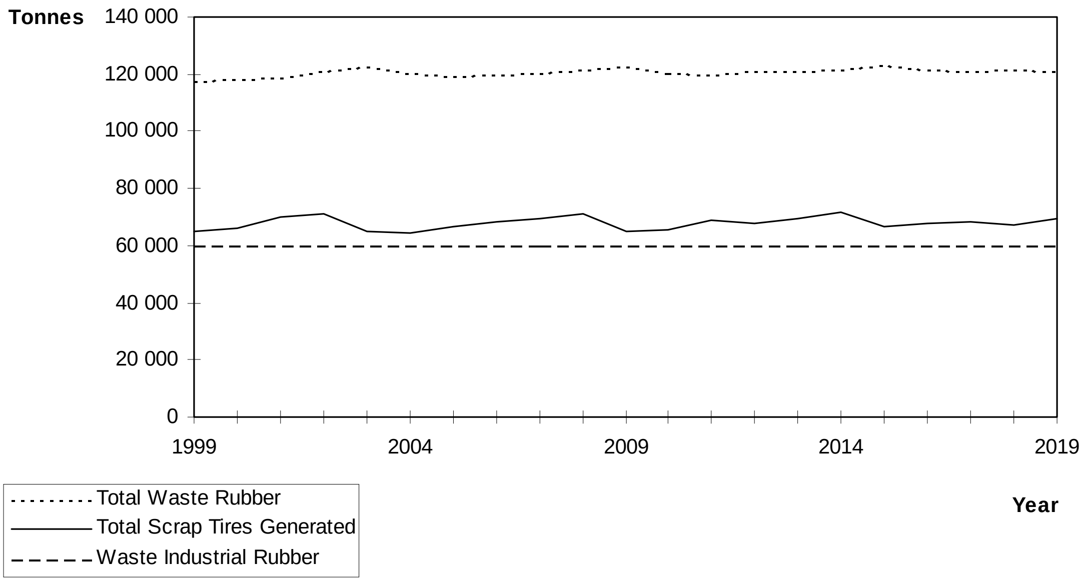


Figure 5.4 Scenario-2 illustrates the scrap tire generation when the number of passenger cars that enter the traffic each year is reduced by 10%. Note that, compared to Figure 5.2 in Scenario-1 (No Changes Scenario), scrap tire generation becomes more stable and reaches 69.4 thousand tones by year 2019 with an increase of only 6.4%.

Results obtained from Scenario-2 are also compared to Scenaro-1's and presented in the following three diagrams. Figure 5.5, Figure 5.6 and Figure 5.7 show the trends in *the demand for passenger car tires*, *the number of estimated scrap passenger car tires* and *the amount of total scrap tires that will be generated* in Scenario 1 and 2, respectively.

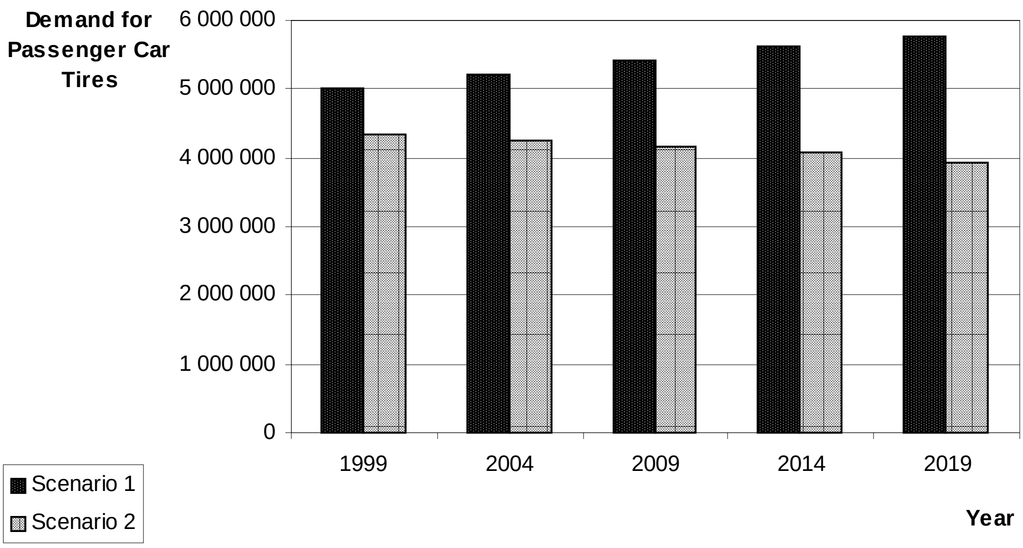


Figure 5.5 Reducing the number of passenger cars entering the traffic each year by 10%, approximately 1 million less passenger car tires is expected to be needed by year 2004. The reductions in the demand for passenger car tires are around 1.3 million by 2009, 1.5 million by 2014 and 1.8 million by 2019.

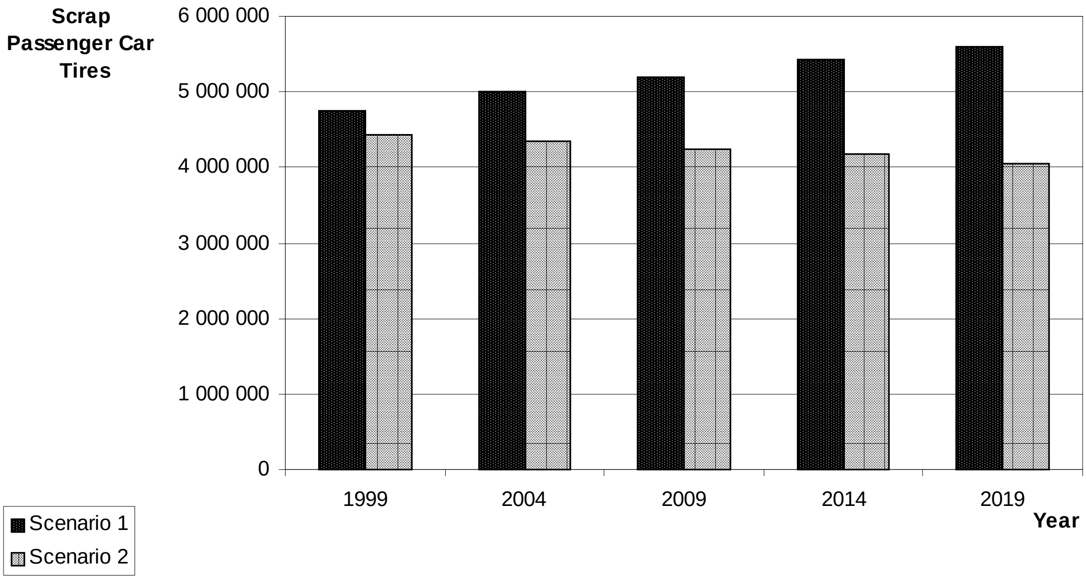


Figure 5.6 A decrease in generation of scrap passenger car tires follows the reduction in the demand for passenger car tires. Scenario-2 estimates that about 0.7 million less scrap passenger car tires are generated by year 2004, where this amount is around 1 million by 2009, 1.3 million by 2014 and 1.5 million by 2019.

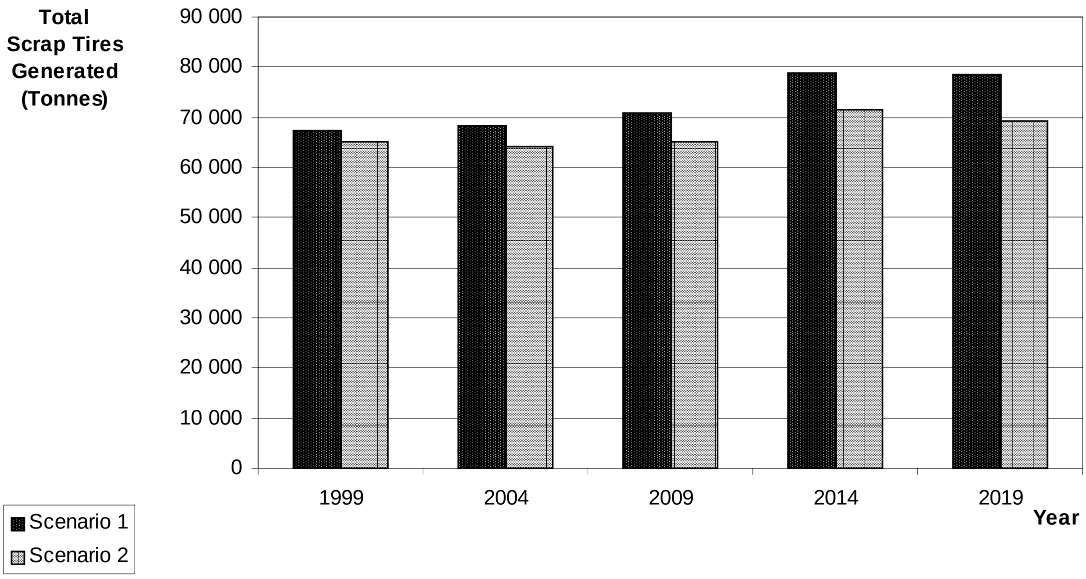


Figure 5.7 Expected decreases in the amount of total scrap tires generated for the next 20 years; about 4 thousand tones in 2004, 6 thousand tones in 2009, 8 thousand tones in 2014 and 9 thousand tones in 2019.

5.4.3 Scenario-3

Scenario-3 illustrates the future trend of scrap tire generation by only reducing the travelling distance of passenger car tires by 10%. This reduction in the travelling distance directly causes a 10% increase in the life span of passenger car tires. With the public awareness in alternative forms of transportation and some simple but important measures (i.e. proper car and tire maintenance, carefully driving), it is not very difficult to achieve a 10% increase in the life span of passenger car tires.
Figure 5.8 shows how 10% reduction in travelling distance of passenger car tires affects the scrap tire and in turn total waste rubber generation.

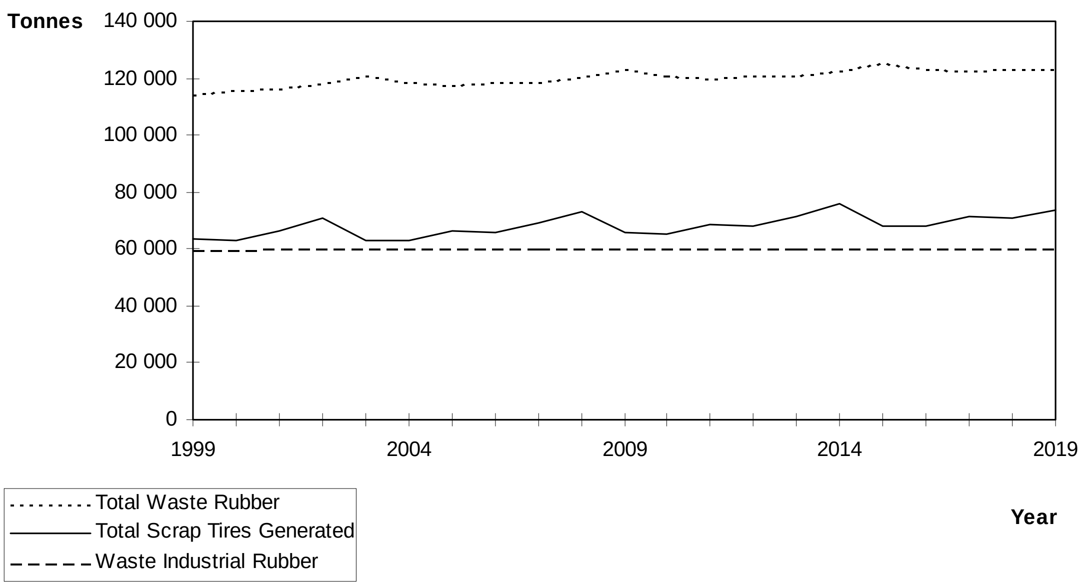


Figure 5.8 Scenario-3 illustrates the trend of scrap tire generation when a 10% reduction in the travelling distance of passenger car tires is achieved. In this Scenario 73.6 thousand tones of scrap tires are expected to be generated by year 2019, which is 15.9% higher than the amount today. Compared with the increase of 16.4% in Scenario-1, this value is slightly less.

Following three diagrams show the changes in the demand for passenger car tires, the number of scrap passenger car tires, and the amount of total scrap tires generated, respectively.

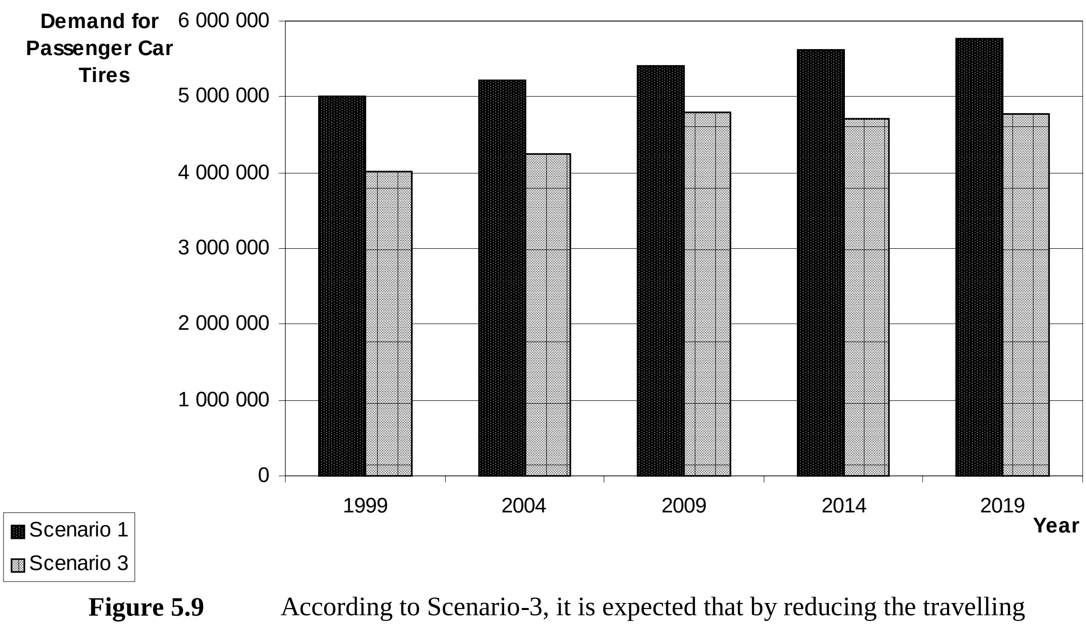


Figure 5.9 According to Scenario-3, it is expected that by reducing the travelling distance of passenger car tires 10%, approximately 1 million less passenger car tires will be needed by year 2004. The reductions in the demand for passenger car tires is around 0.7 million in 2009, 0.9 million in 2014 and 1 million in 2019.

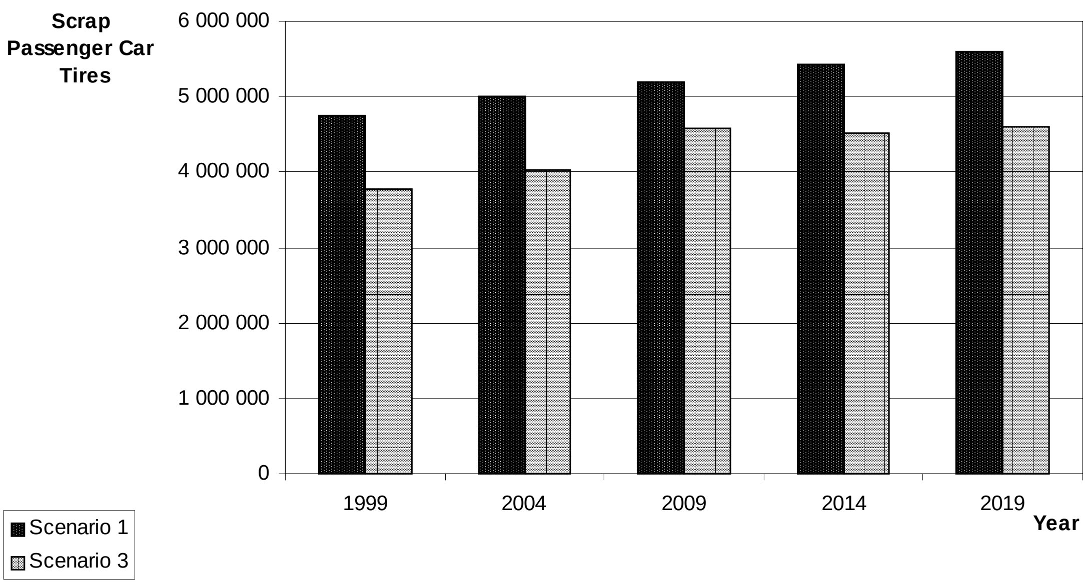


Figure 5.10 In Scenario-3, about 1 million less scrap tires is expected to be generated by year 2004, where this amount is 0.6 million by 2009, 0.9 million by 2014 and 1 million by 2019.

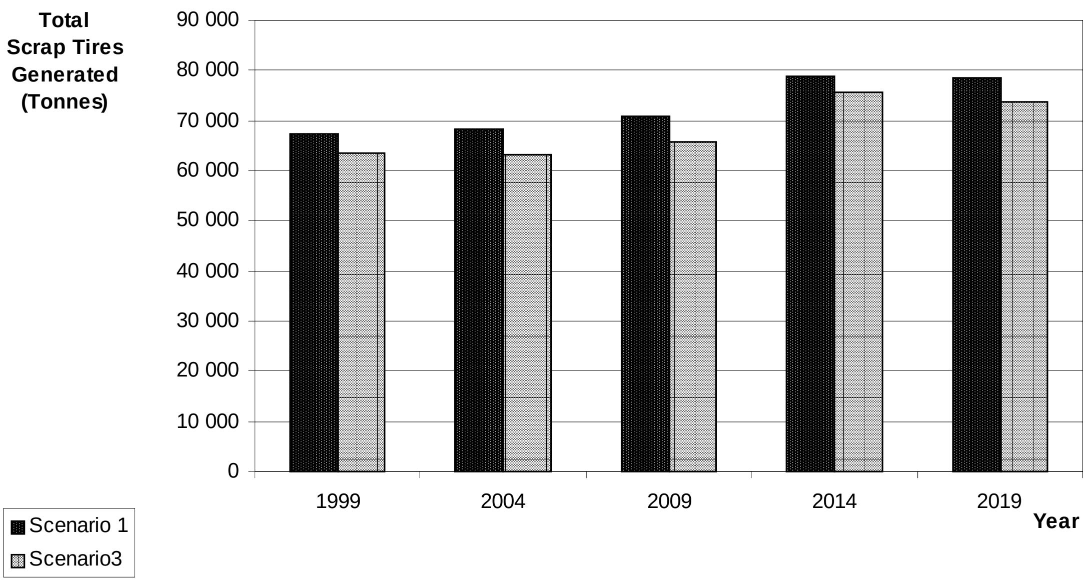


Figure 5.11 Compared to Scenario-1, Scenario-3 shows that 10% reduction in the travelling distance of passenger car tires leads an average reduction of 5 thousands tons in total scrap tire generation.

5.4.4 Scenario-4

According to 1998 values, retreading rate of passenger car tires is 8.5% of all scrap tires collected in Sweden. With the model developed, it is calculated that this amount corresponds to 15% of the scrap passenger car tires. Swedish retreading industry, with 15% retreading rate, supplies only half of the market demand for retreaded tires. Other half is imported from other countries.

Running the model with a retreading rate of 17% (of total scrap tires collected - which also corresponds to 30% of scrap passenger car tires), the situation of scrap tire generation is illustrated in Figure 5.12.

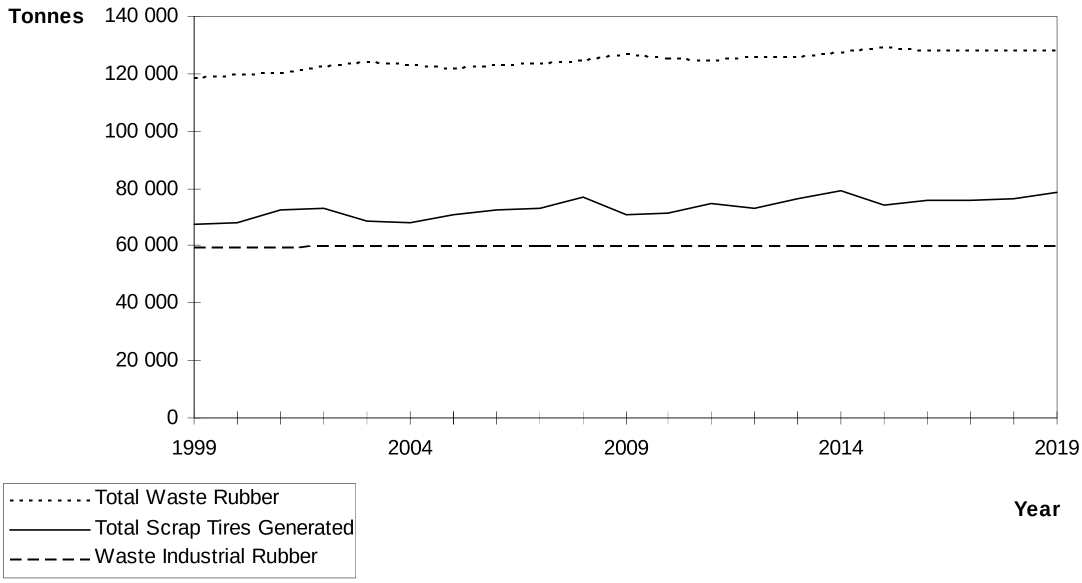


Figure 5.12 Compared to Figure 5.2 in Scenario-1, this figure shows that there is no difference in the trend of scrap tire generation when the retreading rate of passenger car tires increases to 30% from 15%. However, if this rate exceeds 30%, then with increased number of retreaded tires the demand for new tires could decrease causing also a reduction in the increase of scrap tire generation (See Section 5.5 for more details).

Although, doubling the retreading rate of passenger car tires does not effect the scrap tire generation, it changes the waste rubber management patterns. As retreading rate increases, activities in other options in dealing with waste rubber will eventually decrease. In this Scenario, this decrease is assumed to be on export rate of the scrap tires that are relatively in good condition. The main reason behind this assumption is that, with increased retreading rate, there would be more demand for these scrap tires from Swedish retreading industry. And it is very likely that this demand could lead to a decrease in the export rate. Figure 5.13 shows these expected changes in waste rubber management.

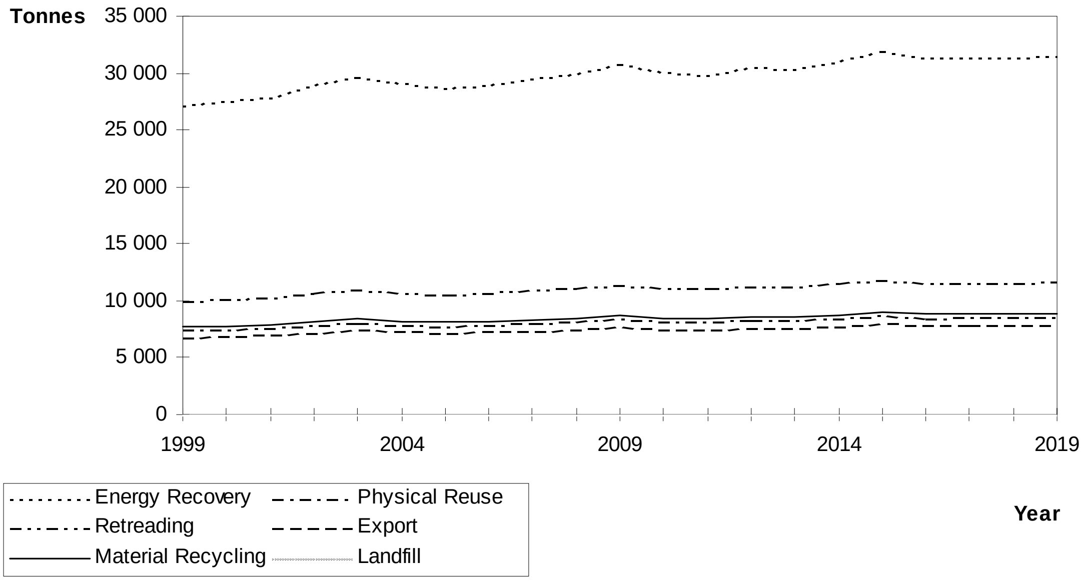


Figure 5.13 Compared to Figure 5.3 in Scenario-1, by increasing retreading rate of passenger car tires to 30%, the amount of tires that are retreaded increases to 10 thousands level, where the exported amount decreases to 7 thousands level.

Following Figure shows the amounts of retreaded passenger car tires with retreading rates of 15% and 30%.

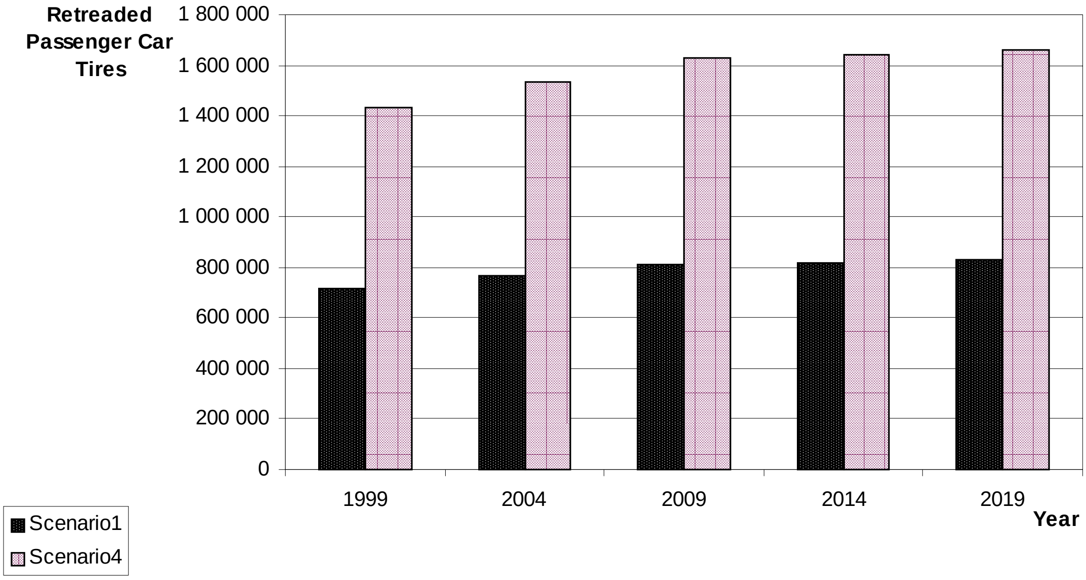


Figure 5.14 Today, retreading industry only meets half of the Swedish drivers' demand. By increasing the retreading rate of passenger car tires to 30%, Swedish retreading industry can supply other half of the demand, which is currently being imported.

5.4.5 Scenario-5

Scenario-5 presents the expected changes in the waste rubber management when 25% material recycling rate of scrap tires is achieved with the possible expansion of new recycled rubber content products and applications.

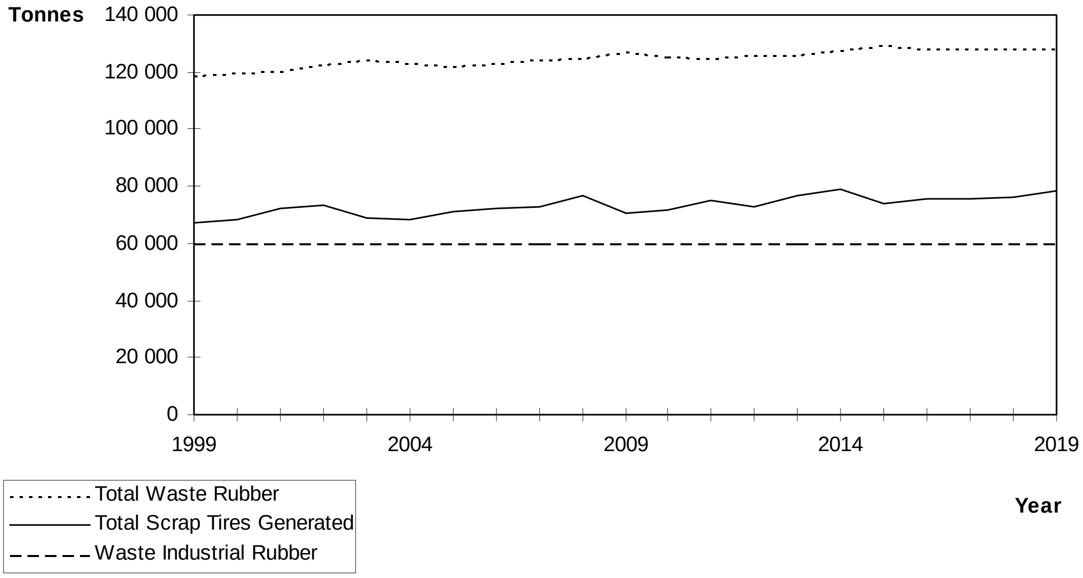


Figure 5.15 Increased recycling rate does not effect the waste rubber generation. Compared to Figure 5.2 in Scenario-1, the amount of waste rubber generated is the same no matter how much the recycling rate increases.

Certain changes in the amount of recycled scrap tires and primary raw material usage in industrial rubber product manufacturing are illustrated in Figure 5.16 and Figure 5.17, respectively.

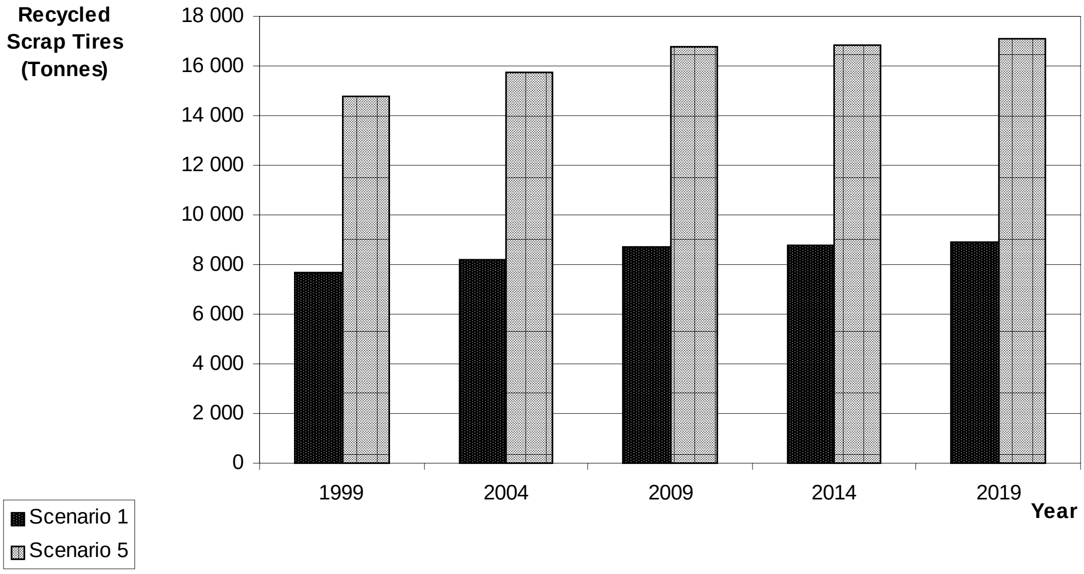


Figure 5.16 By increasing the material recycling rate of scrap tires to 25%, 7.6 thousand tones of more scrap tires could be recycled by year the 2004, 8 thousand tones by 2009, 8.1 thousand tones by 2014 and 8.2 thousand tones by 2019.

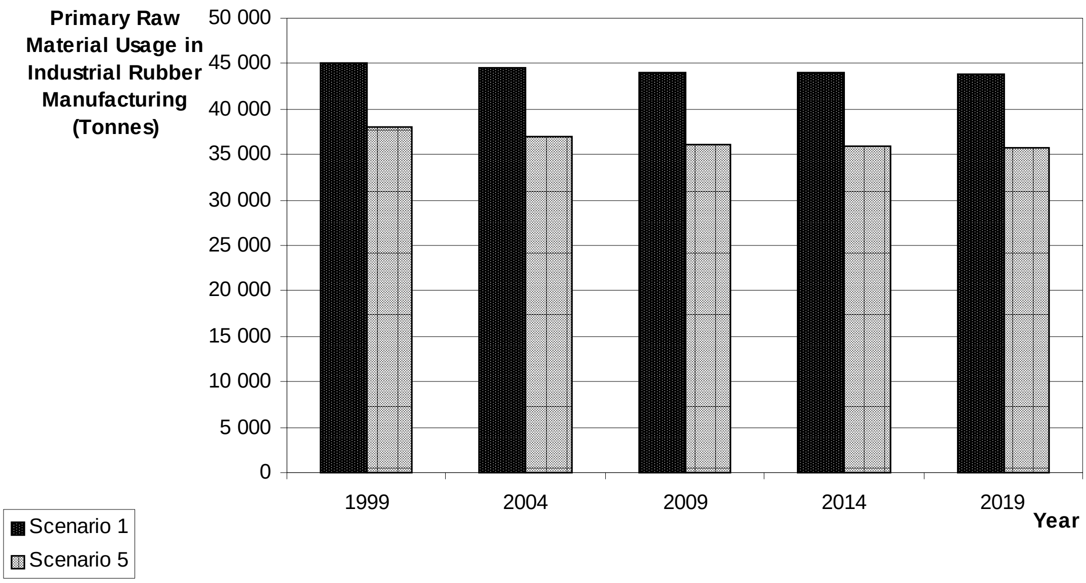


Figure 5.17 Use of recycled rubber as a secondary raw material in manufacturing of different industrial rubber products, decreases the amount of primary raw material usage.

5.4.6 Scenario-6

Scenario-6 considers the possible EU landfill directive that could come into action by year the 2003 and ban the disposal of scrap tires in landfills. Figure 5.18 shows the expected scrap tire generation after this possible ban.

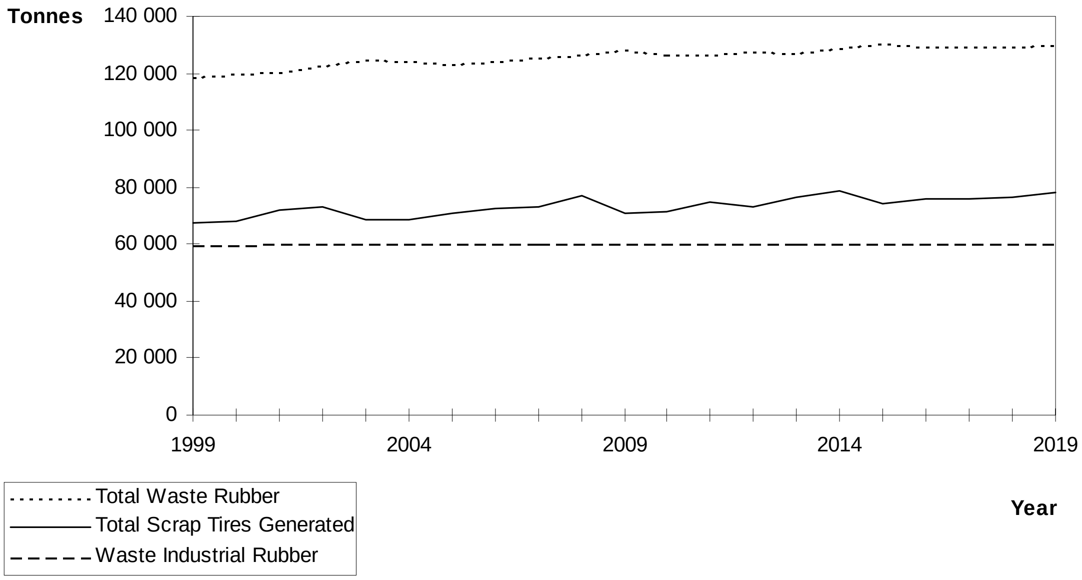


Figure 5.18 Compared to Figure 5.2 in Scenario-1, a possible ban for landfilling of scrap tires does not effect the scrap tire generation and thus the amount of total waste rubber.

With only 2% landfilling rate, Sweden’s waste rubber management system will not be affected by this ban. Figure 5.19 shows the small changes in the treatment patterns of scrap rubber.

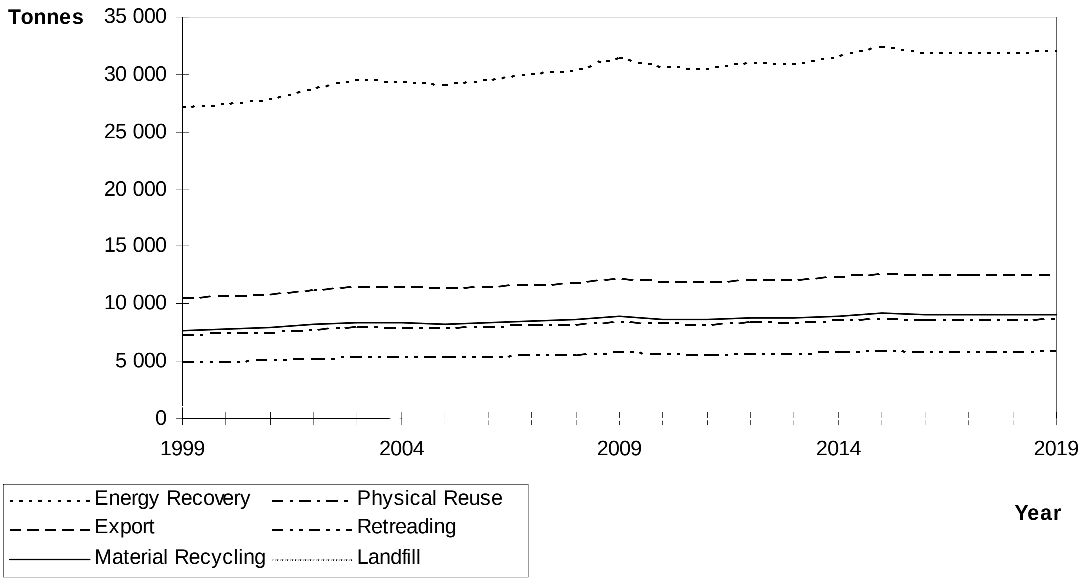


Figure 5.19 Compared to Figure 5.3 in Scenario-1, possible EU landfill directive will cause slight increments in the increase rate of the current waste rubber management practices. With the ban for landfilling, an amount of around 1500 tones of scrap tires that used to be disposed cannot be landfilled anymore and will be managed by other alternative ways.

5.4.7 Scenario-7

The last scenario presents how the waste rubber management in Sweden will be effected if 25% of industrial rubber production is replaced with TPE production. Today only around 12% of industrial rubber products are manufactured from TPEs. With increased research and development it is highly likely that this rate will increase. This scenario illustrates such an increase based on the assumption that all products manufactured from TPEs are being recycled at the end of their service lives.

Figure 5.20 shows the general trend of total waste rubber generation in the following 20 years.

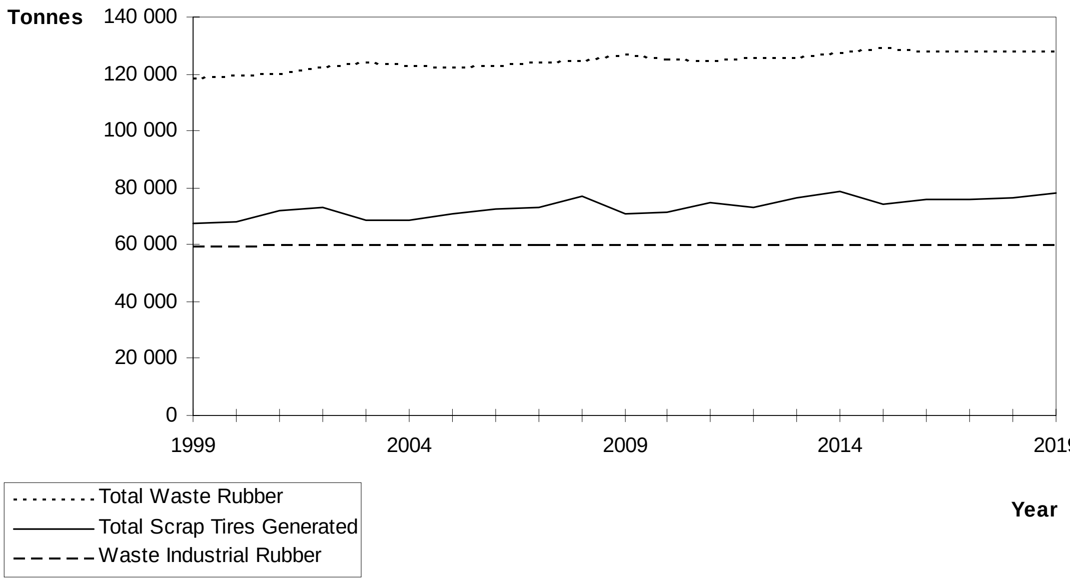


Figure 5.20 It is assumed that each year 60 thousands tones of waste industrial rubber enters to the waste stream. And this waste generation will continue unless a change in demand patterns occurs.

Increased use of TPEs in industrial rubber products also makes it possible to recycle these products and remanufacture with no significant loss in performance. Figure 5.21 gives a comparison of the amount of primary raw material used for industrial rubber products in Scenario-1 and Scenario-7.

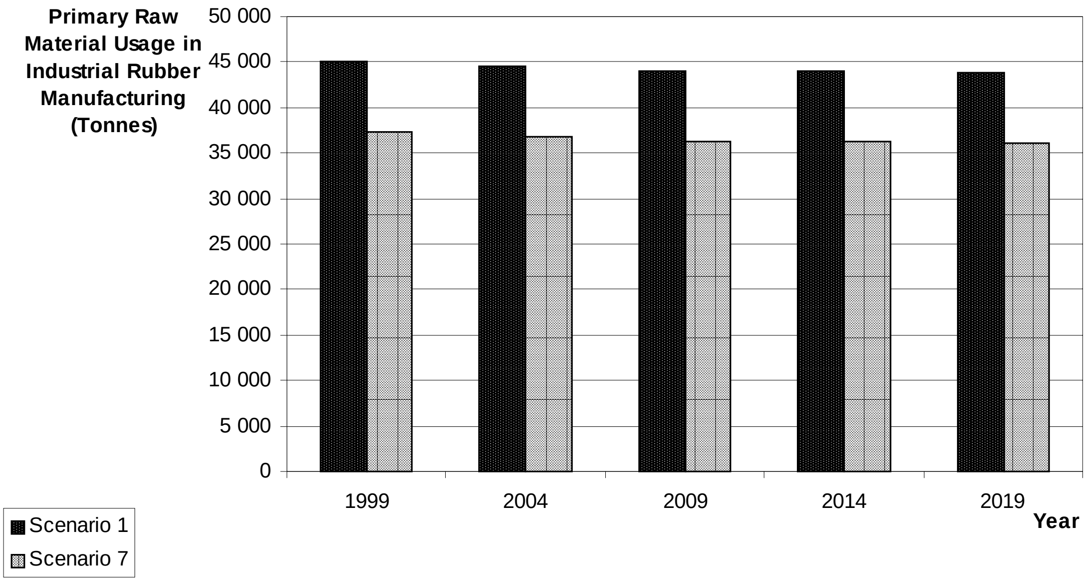


Figure 5.21 Increasing the use of TPEs in industrial rubber production to 25% and recycling all waste TPE products, every year 7.8 thousand tones less primary raw material is used to manufacture various industrial products.

5.5 Summary and Discussion of Scenarios

The analyses of seven different scenarios reveals clearly that Scenario-2 (10% reduction in the number of passenger cars that enter the traffic each year) and Scenario-3 (10% reduction in the travelling distance of passenger car tires) corresponding to two different source reduction practices lead to a direct decrease in the generation of scrap tires (and ultimately total waste rubber). Other scenarios, on the other hand, only illustrate the measures/practices to deal with and reduce the waste rubber that is already generated, and enter to the waste stream.

The changes in Scenario 2 and 3 are expected to occur in other sections of the product chain rather than waste rubber management. However, such changes have consequences directly affecting the waste rubber management part of the chain. Moreover, this sector can have a role to play to realize such changes by improved provision of relevant information regarding the economic, social and environmental issues related to both manufacturing of rubber products and their handling at the end of their service lives. Although Scenario-2 and Scenario-3 reduce the amount of scrap tire generated and are accepted to be as source reduction measures, at this point it would be interesting to ask the question "what the likelihood of achieving such reductions as presented in these scenarios?".

For the case of Scenario-2, for example, "Is it really possible to change the consumption patterns and decrease the number of cars that enter the traffic each year?". At the first glance it seems difficult to achieve such a reduction, but with the growing public awareness compounded with the macro scale policies focusing on the promotion of public transportation, it is not unrealistic that the demand for private passenger cars will decrease.

Reduction in travelling distance, represented in Scenario-3, on the other hand, looks more easy to be achieved. Again with the increased public awareness, it is very likely that the trend to use the alternative ways of transportation (i.e. public transportation, cycling etc.) will continue to grow and this might eventually lead a reduction in the travelling distance of passenger car tires.

Expected increase in retreading rate of passenger car tires, illustrated by Scenario-4, is a matter of both economic initiatives and the level of environmental awareness among Swedish policy makers and drivers. Today, retreading rate for commercial vehicle (i.e. busses and lorries) tires is about 70%. However, this figure is only about 15% for the passenger car tires. Swedish retreading industry only supplies half of the demand where the other half is imported from other countries. This fact clearly highlights the potential to increase the retreading rate up to around 30%. As it is seen from Figure 5.12 in Scenario-4, to increase the retreading rate up to 30%, will only stop the import of retreaded tires, but still the same amount of scrap passenger car tires will be generated. If this rate exceeds 30%, the number of retreaded tires in the market will increase and the demand for new tires will decrease. Such a change can be realized with the measures mentioned in section 3.2.1.

Scenario-5 illustrates the expected situation of waste rubber management with a recycling rate of 25%. The use of recycled rubber in re-manufacturing is increasing with the increased number of new products and application. There is a clear trend towards this direction. Today, it is accepted that, integrated firms that recycle rubber and use it as secondary raw material in their own production and manufacture new products will grow significantly. Such trends have already being observed in other European countries[h] and are likely to occur in Sweden too. Unlike other scenarios, the actual environmental benefits that can be realized with increased recycling rate are related to the production stage rather than waste management due to reduced demand on virgin raw materials.

In near future, Scenario-6 will eventually occur and landfilling of tires will be banned in European Union countries. But it is difficult to conclude that this ban will cause major changes in Swedish waste rubber management system. The main reason for this is that, the amount of scrap tires that are landfilled is small as compared to other management options. In this respect, it is safe to conclude that such a ban will not effect the Swedish waste rubber management significantly.

Effect of increased use of TPEs on waste rubber management, presented by Scenario-7, can be seen as a part of Scenario-5. With the growing trend in recycling of waste rubber, manufacturers will move towards using more easily recyclable products. Consequently, it is possible to expect an increase in the use of TPEs in industrial rubber manufacturing (by the early 21st century the amount of industrial rubber production that will be converted to TPE production is estimated to double itself and reach a value of around 25% of the industrial rubber production in global market[1]). As a simultaneous outcome, growing trend for designing products for easy disassembly and recycle will increase the recycling rate of waste rubber. A combination of Scenario-5 and Scenario-7 is on the way.

[h] In Germany, for example, Poseidon Products GmbH, a joint venture between the American company the Quantum Group Inc., and the German company Strukturentwicklungsgesellschaft [Structural Development Company] Ueckemünde mbH (StEG), will start its facilities when completed in Summer 1999. It will produce ground rubber and manufacture a wide range of value added products as well as will utilize the REVULCON process to enter new and emerging markets including providing material for new tire manufacturing.

CHAPTER 6

GENERAL CONCLUSION

Having addressed and analyzed the possible options in the management of waste rubber, it should be considered that, source reduction/waste prevention is the most desirable option.

In this respect, to deal with the scrap tire issue, more effort is needed to **increase the life span of tires** with improved research and development, reductions in travelling distance, improvements in tire and car maintenance, and with more conscious driving. When talking about waste industrial rubber products, a **switch to TPEs** offers a ready answer for the recycling of material content of these products, thus reduces the amount of total waste rubber. More research and development is needed for different types and applications of TPEs that could eventually increase their use in various industrial rubber products. With the increased use of TPEs, the reutilization problem of many waste industrial rubber products will be solved simply by recycling them. However, since it seems to be impossible to use TPEs in tires in the near future, the scrap tires will continue to be managed by retreading, material recycling and energy recovery.

Compared to other major EU countries Sweden has a lower retreading rate. In order to **meet the EU retreading target**, it is needed to increase the Swedish drivers' awareness for using retreaded tires and to have strict regulations for minimum legal tread depth.

Protecting the environment is becoming increasingly more important. An area, which can bring significant potential benefit to the environment, is **increased waste rubber recycling**. The driving forces for increasing recycling rate are profit opportunity through development of new recycling technologies, recycled content products and suitable markets for such products. One of the important factors to expand markets for recycled materials is to build up demand for the products that have a recycled rubber material content or develop new areas of use and/or promote the existing ones for recycled rubber products. For the latter, automotive industry and construction works in linear systems, such as roads and railways deserve special interest as they offer good potential for new areas of use for recycled rubber. Swedish government should encourage the use of recycled ground rubber in these applications especially in **rubberized asphalt pavements** and various other **civil engineering applications**. These options not only present environmental and economic benefits, but also contribute to the development of rubber recycling industry (currently they operate on very low profit margins, since they use extremely high cost equipment with high running costs to produce a relatively cheap product) which can create new job opportunities.

To create a sustainable rubber industry in Sweden, there is a need for active participation and co-operation of all major stakeholders. In this respect, different than many other countries, the voluntarily introduced management system for scrap tires by Swedish rubber industry is a successful system that can be seen as a good example of such participation and co-operation. This system works effectively mainly due to effective involvement and serious dedication of different parties from tire industry and key stakeholders. However, in order to bring the Swedish rubber industry to a well-prepared position to deal with the problems related to waste rubber in a more sustainable way there is a need to:

1. promote and increase recycling of rubber instead of focusing too much on energy content recovery, and;
2. pay more attention to the establishment of a similar waste management system for collection and handling of industrial rubber products.

Such initiatives, however, require further research and study on:

- the economic benefits of increased recycling and the use of these recycled materials as secondary raw material in re-manufacturing, preferably by using another model developed by software Stella 5.1.1u.
- the establishment of the waste management system for industrial rubber, addressing the necessary attributes of different elements of the system such as collection, sorting, etc.

APPENDICES

APPENDIX 1

Table 2.1 Properties of different rubber types

Property	Natural Rubber(NR) / Isoprene Rubber (IR)	Styren Butadiene Rubber (SBR)	Butadiene Rubber (BR)	Ethylene-Propylene Rubber (EPM/EPDM)	Butyl Rubber (IIR)	Choloro -prene Rubber (CR)	Nitrile Rubber (NR)	Silicone Rubber (PMQ)*
Max T (F)	176	194	176	248	194	185	194	392
Min T (F)	-58	-40	-103	-31	-49	-31	-22	-112
Tear Strength	4	3	3	3	3	3	3	1
Abrasion resistance	4-5	4-5	5	3	3	3-4	3	1-2
Oil/fuel resistance	1	1	1	1	1	2-3	3-4	2-3
Weather/ozone resistance	1-2	11-2	1-2	5	4	3	1-2	5
Water Swelling	4	4	4	5	4	2-3	3-4	2
Fire Resistance	1	1	1	1	1	3	1	2
Rebound at low T	5	3	3	3	1	3	3	5
Rebound at high T	5	3	3	3	3	4	3	5
Fatigue	4	4	4	4	3	4	2	1-2
Bonding to metal	4-5	4-5	4-5	3	2	4	4	2
Bonding to textile	4-5	4-5	4-5	3	2	4-5	3-4	2

Source: http:www.trelleborg.com/indexx_eng.html

Grading of Properties; 5 excellent, 4 very good, 3 good, 2 satisfactory and 1 poor
* To show the large variation between the various types silicone rubber is also included as an example.

APPENDIX 2

Extrusion

Long length products such as profiles and tubes are formed by extrusion. The same method is used for making other products such as treads for tires. The extruder used has the same principle as a meat-mincer, with a screw feeding the compound through a die. The compound is heated by the friction and the extruder is cooled with water. When the profile has passed the die, it will, if going to be vulcanized in an autoclave, be cooled in water. Another method is to vulcanize continuously in a microwave-heated oven or in a salt bath.

Spreading

At the start of the rubber industry in the 1800s, a high demand product was waterproofed textiles, and the spreading technique developed early. A rubber compound is dissolved in an organic solvent and spread on the textile with a knife. After the solvent has been evaporated a rubber film has been formed on the textile, and the coated fabric is cured in a hot oven.

Calendering
In production of sheets or textile coated with rubber thicker than what is achieved by spreading, the calendering technique is used. Typical articles are parts for tires, conveyor belts, hoses as well as sheeting and mats.

A calender is a roller mill with two or more rolls. The number of rolls and the configuration depend on the type of operation. 4-roller mills are common for coating of textile and for precision calendering of rubber.

The compound is pre-heated on a mill or in an extruder and fed to the calender. As the rolls rotate in different directions, the compound is pressed and headed forwards. When calendered to final thickness the material is cooled in air before being wound up on to rollers.

When coating textile, the fabric is fed between the last two rollers.

Mould Curing
When making parts with complicated designs and with small tolerances, mould curing is used. Examples of products are seals and other parts for the automotive industry. Several principles are used. But generally the compound has to fill a cavity and the curing is made directly in the mould by heating it up.

As the rubber has about 2 % higher heat shrinkage than steel, the cavity must be bigger than the ready part to give it the correct dimensions. The cavity will be a little bit over-filled and the material forms a flash on the outside of the product. For economical reasons, the flash has to be minimized.

- **Compression moulding**
  The oldest method is compression moulding, where a mould consisting of two parts is mounted in a press. A preformed rubber block is placed inside the cavity and when the press was closed the mould, the rubber fills the cavity. To make sure that the product is perfect there must be some overflow. The curing time is rather time-consuming and gives much flash. The advantage is the simplicity of the method and it is well suited for larger products. The requirements of the compounds are less than in other methods.

- **Transfer moulding**
  Some of the drawbacks with compression moulding are overcome with transfer moulding. The compound is placed into a third part of the mould - a heating chamber - and by closing the press the rubber is injected into the cavity with a piston. The preheating gives a shorter curing time and the risk for porosity, etc., is low. The flash can be minimized by having the correct injection pressure. The bonding is imposed on rubber-metal parts by transfer moulding. The method cannot be used if fabric has to be inserted in the products. The moulds are more complicated and therefore more expansive.

- **Injection moulding**
  With injection moulding the compound is extruded with a screw into a closed cavity. The extrusion pre-heats the rubber and shortens the curing time. The process puts high requirements on the compound regarding flow properties and curing behavior. The biggest advantage with injection moulding is the possibilities to automate the process and the control of the flash. An injection machine is rather complicated and the whole process is more technically developed. Laminated products can not be manufactured by injection moulding.

Postcuring
Rubber products cool down slowly and the vulcanization proceeds even after the product has been demoulded. The postcuring process is normally around 10 % of the total curing. A few special compounds require postcuring in hot air for several hours, sometimes up to 24 hours.

APPENDIX 3

Table 3.3 Some of the automotive parts that will possibly be affected and converted to TPEs.

Part Type	TPE Examples
Easy accessible and removable parts	TPE body seals substituting for EPDM
Large parts	Bumper Fascia
Monomaterials constructions	-All polyolefin door trim panels -All thermoplastic body seal/fastener systems
Incorporation into parts which must be removed	Airbag doors

Source: Reference No. 15

Table 3.4 Some of the specific properties and advantages of using shredded tires used in civil engineering applications.

Properties	Advantages
Lightweight	They weigh less than half of what soil weighs. They have low earth pressure so that they don't apply a force to the structure that they are used in (i.e. when they are used behind a wall, they don't push on that wall very hard)
Good thermal insulator	They are 8 time better than soil in terms of thermal insulation and limit frost penetration to a roadbed
Compressible	75 scrap tires can be used in one cubic yard (0.76 m^3) of space
Cheap	They are often the cheapest solution to a civil engineering problem

Source: Reference No. 24

APPENDIX 4

Table 3.5 Relation between mesh size and μm

Mesh Size	μm
10	2000
20	850
40	425
50	300
60	250
80	180
100	150
200	75
400	38
500	20

Source: U.S Bureau of Standards

APPENDIX 5

Fully Integrated Cryogenic Scrap Tire Recycling System;TCS-1 System

In Tirex's fully integrated Cryogenic Scrap Tire Recycling System, called TCS-1, processing of scrap tires starts with a front-end preparation module capable of processing up to five tires per minute. First, the tread part of the scrap tires is separated from the potentially more valuable side-wall sections. Separated tire sections are then cut into one foot (0.305 m) segments and feed into a freezing chamber, which produces a compressed stream of air cooled greater than 200 ^{o}F below zero (-129 ^{o}C). When the tire segments are frozen, they are crushed into tiny particles with the help of a disintegrator.

Processed ground rubber which is not contaminated by fiber and metal particles and of varying degrees of fineness down to 40 mesh, clean steel wire and sections of undamaged fiber cord are the final products of the TCS-1 System. In this "closed loop" processing system, there is no use of chemicals, solvents, gases or other substances, which could result in emissions of any kind.

APPENDIX 6

Table 3.6 Profile of Mechanical Grinding

Mechanical Grinding	
Feedstock	Whole or cut car, light utility, heavy goods tires and/or Production waste and stripped treads and/or Inner tubes
Annual Capacity	± 20,000 t/y
Energy Use	125kwh/t
Man Power	Intensive: ± 5-6 man team per shift
Production	Input : 3.5 ton Output: 2.5 ton (crumb) and 1.0 ton (steel)
Equipment	Conveyors, mechanical shearing/grinding equipment with magnetic and air separators
Number Of Operations	3
Processes	Sort, Cut (optional), Feed First pass through shredder (reduction to ± < 30mm) Magnetic separation of metals Air separation of textiles Optional: Second pass for further reduction to desired size Packaging (bagging), disposal of metals (if possible sale) Disposal of fluff Separation efficiency: 100%for rubber, metals, textiles Purity of rubber granulate: <0.005%of residual materials
Product Characteristics	Irregularly shaped particles due to shearing
Product Sizes	Rough 7.0 mm to 25.0 mm 2.0 mm to 7.0 mm 0.5 mm to 2.0 mm Fine 0 mm to 0.5 mm
Uses	7-15 mm: preparation for transporting, fuel for incineration, material for found barriers 2-7 mm: drainage, light-weight road bed fill, playgrounds, tram and rail beds 0.5-2 mm: asphalt, manufactured products, carpet underlay, moulded products, train and tram rails, running tracks, shoed soles, brake linings, carpet backing tires, interliners, belting, cables, friction materials, 0-0.5 mm: compound ingredient for tires, road paving materials, many other industrial rubber products
Emissions	SO_x: 0 NO_x: 0 Dust: 0.2 kg/h
Comments	• High maintenance due to blade sharpening and replacement • Odorless • High yield of high quality product

Source: European Tire Recycling Association (ETRA). Adapted from reference No.40.

Table 3.7 Profile of Cryogenic Grinding

Cryogenic Grinding	
Feedstock	Granulated car, light utility, heavy goods tires and/or Production waste and stripped treads and/or inner tubes
Annual Capacity	± 2,000 t/y
Energy Use	150 kWh/t (plus costs of liquefying the nitrogen)
Liquid Nitrogen Use	0.5 kg per kg crumb
Man Power	Limited: 2 man team per shift
Equipment	Conveyors for feed, size reduction equipment, Mill, Heat exchanger, Chamber to cool chips to -120^{o}C, Shifting equipment
Production	Input : 1.0 ton Output: 1.0 ton crumb from separated granulate
Number Of Operations	2 for pre-treated material
Processes	Conveyor for feed Nitrogen treatment for fragmentation Further reduction to desired size Separation Milling Packaging (bagging) Separation efficiency: 100% for rubber, metals, textiles Purity of rubber granulate: < 0.05% of residual materials
Product Characteristics	Evenly shaped particles due to fracture rather than shearing
Product Sizes	Rough: 2.0 mm to 5.0 mm 0.5 mm to 2.0 mm Fine: 0 mm to 0.5 mm
Uses	2-5 mm: drainage, road bed fill, playgrounds, tram and rail beds 0.5-2 mm: asphalt, manufactured products, carpet underlay, moulded products, train and tram rails, running tracks, shoed soles, brake linings, carpet backing tires, interliners, belting, cables, friction materials, 0-0.5 mm: compound ingredient for tires, road paving materials, many other industrial rubber products
Emissions	SO_x: 0 NO_x: 0 Dust: 0.4 kg/h
Comments	High cost of liquid nitrogen High product yield Completely odorless Lower maintenance due to reduced equipment wear

Source: European Tire Recycling Association (ETRA). Adapted from reference No. 40

APPENDIX 7

OK (Ozone-Knife) Technology

This new technology called Ozone Knife, is a separation method to break down scrap tires right down to their basic components simply by using pure Ozone gas. If rubber is exposed to pure Ozone gas, Ozone gas attacks rubber hydrocarbon molecules and breaks the bonds between the chain of molecules in a very short time.

In this technology, scrap tires are processed under stress in a pure ozone environment. By this way, the breaking apart process accelerates, and the bonds between the rubber hydrocarbon molecules are broken faster. After separated from supporting structures like steel wires or fiber, pure ground rubber becomes ready for different ways of re-manufacturing. One of the biggest advantages of this recycling technique is that, the properties of recovered ground rubber (< 30 µm) are chemically and physically unchanged and equal to the raw material, which makes it possible to be remanufactured even requiring vulcanization / molding.

The Research Center for Analysis, Radiometry and Environmental Technology in Germany verifies, rubber broken down by ozone is usable for the manufacture of rubber products requiring vulcanization / molding. OK-Technology has been today tested, and verified by German Industry and is fully accepted for the manufacture of new rubber related products, and suitable for a great many new applications requiring vulcanization / molding.

This technology also requires up to 60 % less energy compared to mechanical grinding technique and at present, it is possible to process up to 5000 kg of scrap tires per hour which make it easier to recover the running costs.

APPENDIX 8

Table 3.10 Natural rubber reclaim is widely used in the rubber manufacturing industry due to its positive influences on the processing behavior of a compound.

Advantages of Natural Rubber Reclaim
Shorter mixing cycles
Lower mixing, calendering and extrusion temperatures
Improved penetration of fabric and cord
Lower swelling and shrinking during extrusion and calendering
Lower raw material costs
Better air venting properties

Source: Reference No. 37

APPENDIX 9

Table 3.11 Profile of energy recovery in cement kilns

	Energy Recovery in Cement Kilns
Feedstock	Whole, cut or shredded light utility, heavy goods tires
Annual Capacity	± 20,000 t/y
Energy Use	30-50 kWh/t
Man Power	Automated: 1 person per shift
Equipment	Conveyors Preheater/precalcinator kiln Rotary furnace (or other design) Incinerators Flue gas cleaners and electrostatic precipitator filtration systems
Production	Input : 12 t/h Output: 32 MJ/kg 800 kcal/kg clinker (or 120 kcal/kg cement)
Number Of Operations	2-3
Processes	Sorting of whole tires and/or pre-treating into shred Direct, continuous feed by automated conveyors Incineration Continuous cleaning of flues and screens Optional: Heat recuperation and circulating system Optional: Electricity generation and utilization
Product Characteristics	Improved cement hardness from tire materials, particularly metals and chemicals Sulfur dioxide and nitrogen oxides from the tires are neutralized by the lime used in the cement and improve its quality
Uses	All cement applications for construction, etc. Heat and energy for plant operations
Emissions	SO_x: 10 kg/h NO_x: 6 kg/h Ash: 250 kg/h Other: 20 kg/h inert fillers
Comments	• High maintenance due to cleaning / replacement of filters and flue gas scrubbing • Improved heating qualities from the tires • There is considerable pressure for cement kilns to comply with new emission regulations • The number of continuous plants has diminished during the past 3 years due to changing emissions standards

Source: European Tire Recycling Association (ETRA). Adapted from reference No. 40

APPENDIX 10

Table 3.12 Profile of energy recovery in steam generation

Energy Recovery in Steam Generation	
Feedstock	Whole or cut light utility, heavy goods tires
Annual Capacity	± 20,000 t/y
Energy Use	50 kWh/t
Man Power	Automated: 1 person per shift
Equipment	Conveyors Optional pre-treatment equipment Preheater/precalcinator kiln Furnace (several designs are available) Incinerators Flue gas cleaners and electrostatic precipitator filtration systems
Production	Input : 12-13 t/h Output: 38.6 t/h steam working pressure 70 bar g superheat temperature 520 ^oC feed water temperature 109 ^oC pressure in condenser (absolute) 135 mbar external temperature 12 ^oC turbo generator 9.7 MW
Number Of Operations	2 (optional pre treatment)
Processes	Automated feed and operation Optional pre cutting or shredding
Product Characteristics	High quality, clean burning energy Better and cleaner than coal and equivalent to other heating fuels
Uses	Steam: Plant heating or sharing with nearby facilities Steel : Has the same specification as high quality scrap and is recyclable Zinc Oxide: Chemical industry Calcium Salts: Chemical industry
Emissions	SO_x: 6 kg/h NO_x: 10 kg/h Ash: 250 kg/h Other: 20 kg/h inert fillers
Comments	• Low maintenance of filters, gas scrubbing • 20% more heat value than fossil fuels • 40% less ash and 20% less emissions than other fuels • Used in Sweden, Germany, Belgium, United States, Japan, South Korea and UK • As concerns over emissions controls have increased there has been considerable pressure to have theses furnaces comply with new regulations • New installations are hampered by the NIMBY (Not In My Backyard) principle

Source: European Tire Recycling Association (ETRA). Adapted from reference No. 40

APPENDIX 11

Table 3.13 Profile of energy and material recovery from pyrolysis.

Energy and Material Recovery from Pyrolysis	
Feedstock	Shredded car, light utility, heavy goods tires, other rubber although more dependent on passenger car tires
Annual Capacity	± 15,000 t/y
Energy Use	50 kWh/t
Man Power	Moderate: 2-3 person per shift
Equipment	Pyrolysis furnace heating at 450-500 °C Post cracking furnace heating at 700-800 °C or, a one step furnace heating at 550-600 °C Heat exchanger and condensing scrubbers Magnetic separator for metals Pyrolytic reactor
Production	Input : 1 t/h Output: 330 kg/h Carbon black 350 kg/h Pyro-oil 148 kg/h Gas 120 kg/h Steel 52 kg/h other
Number Of Operations	5
Processes	Optional pre-treatment of tires Semi-continuous or continuous feed Heating to 450-500°C, post cracking heating to 700-800°C or, a one step process at 550-600 °C Steam activation for carbon residue Magnetic separation of metals, air removal of fibers Oil filtration Packaging of carbon black, oil and steel
Product Characteristics	Commercial grade carbon black after treatment Filtered oil with similar viscosity and calorific value as diesel with a higher aromatic content Steel has the same specification as high quality scrap
Uses	Carbon black: The tire and automotive industries; paint and printing industries; retreading industry for retread replacement; pretreatment of heavily polluted water; asphalt modifiers and fillers; coloring agents for the plastic industry; recarburiser for the steel industry For plant heating and drying processes Gas: As a substitute for No. 6 fuel oil Heavy Oils: As a petrochemical feedstock Benzene & Toluene: Independently recycled Steel:
Emissions	SO_x: 2 kg/h NO_x: 2 kg/h Dust: 1 kg/h
Comments	Limited maintenance

Source: European Tire Recycling Association (ETRA). Adapted from reference No. 40

APPENDIX 12

Table 3.14 Landfill Directive about the Disposal of Tires

Date	Action
May 1996	The European Parliament rejected the first Proposal on landfill because it did not find the level of environment protection in the common position.
June 1996	The Council invited the Commission to present a new Proposal as soon as possible.
1997	The Commission prepared a revised Proposal which was submitted to the Council in December 1997..
16 December 1997	The Council succeeded in reaching a political agreement but extensively amended the Proposal.
21 January 1998	The Environment Committee of the EP voted the new Proposal.
16-20 February 1998	The Plenary session voted the Proposal in first reading and prohibited giant tires to go to landfill.
23 March 1998	The Environment Council adopted a political agreement following the EP decision on the ban of landfilling for giant tires.
3 June 1998	The Environment Council adopted a common position on the proposed Directive authorizing tires used as engineering material and giant tires not to go to landfill.
21 January 1999	The amendment prohibiting giant tires to go to landfill is not submitted to vote.
9 February 1999	The amendment prohibiting giant tires to go to landfill is not submitted to voted in plenary session of the second reading
22 June 1999	Final adoption at the Council. No change should occur concerning tires further to the EP vote i.e. "Member States shall take measures in order that the following wastes are not accepted in a landfill: "…..whole used tires from 2003 excluding tires used as engineering material, and shredded used tires in 2006 (excluding in both instances bicycle tires and tires with an outside diameter above 1400mm)…."

Source: Bureau de Liason des Industries du Caoutchouc (BLIC)

APPENDIX 13

Swedish Environmental Legislation: Waste Disposal, Stockholm 1996

Ordinance (1994:1236) on Producers' Responsibility for tires.

Section 1: This ordinance governs the responsibility of producers from 30 September 1994, in an environmentally acceptable manner, to dispose of tires, which have become spent.

The aim of this ordinance is that of the total amount of tires returned annually:

- 60 percent shall not be disposed of in landfills after 31 December 1996 and
- 80 percent shall not be disposed of in landfills after 31 December 1998

Section 2: Tires, in this ordinance, means tires for cars, trucks, busses, motor cycles. Tractors, off-road vehicles, motorized equipment, trailers and towed machinery.

Section 3: Producer, in this ordinance, means anyone who manufacturers, imports or sells tire.

A producer also includes anyone who manufactures, imports or sells vehicles or equipment referred to in section 2 which are equipped with newly manufactured tires.

Any person, who retreads a tire but does not sell it further, is deemed not to be producer for the purposes of this ordinance.

Section 4: A producer shall accept spent tires and ensure that the tires are recycled or that the materials or energy is recovered or that they are otherwise disposed of in an environmentally acceptable manner.

A producer shall provide information concerning the return of spent tires and facilitate the return of such tires by anyone in possession thereof.

The National Environmental Protection Agency may issue further regulations with respect to the obligations referred to in the first and second paragraphs.

Section 5: A producer shall furnish the National Environmental Protection Agency with;

1. Information concerning the results of reuse and recycling as well as other circumstances relating to the final disposal of tires;

2. Information concerning the number of tires received and other information required in order to confirm that the levels set forth in section 1, second paragraph, are reached.

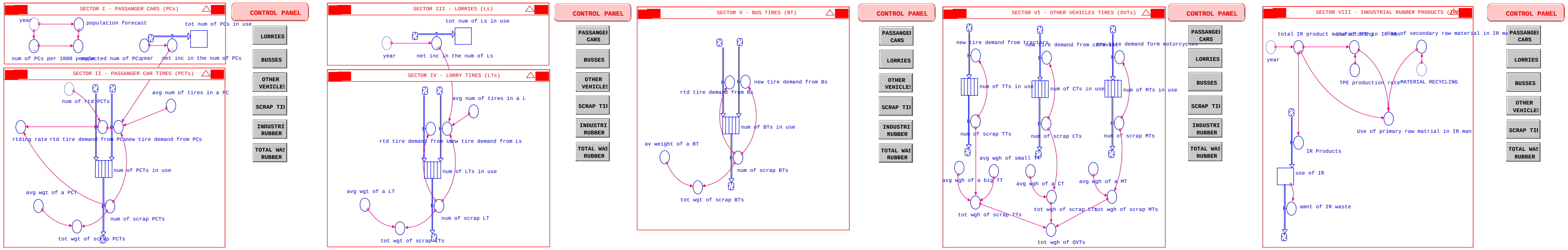
The National Environmental Protection Agency may issue further regulations with respect to the obligations referred to in the first and second paragraphs.

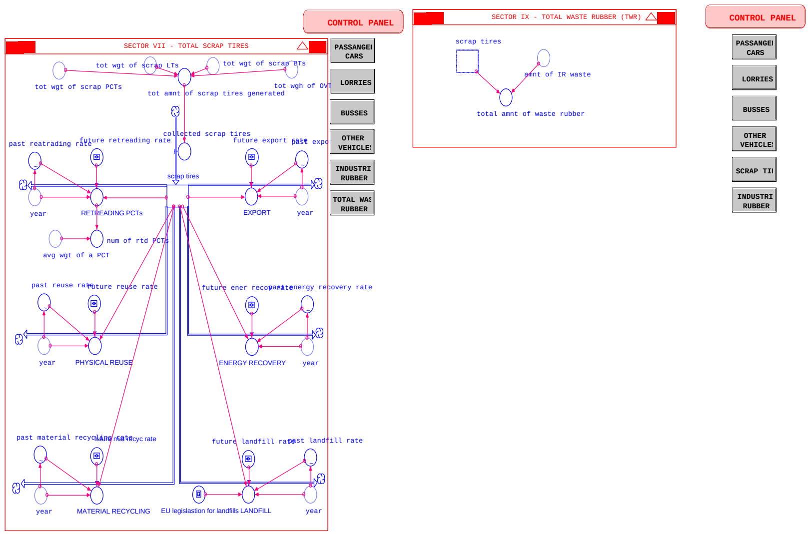
Section 6: Section 24 of the Waste Collection and Disposal Act (1979:596) contains provisions concerning liability for breech of the provisions contained in sections 4&5.

Sections 23-24 of the Waste Collection and Disposal Act contain provisions concerning supervision and compliance with this ordinance.

Section 7: The National Environmental Protection Agency may issue further regulations with respect to implementation of the provisions of this ordinance.

APPENDIX 14


SECTOR I - PASSANGER CARS (PCs)
SECTOR II - PASSANGER CAR TIRES (PCTs)
SECTOR III - LORRIES (LS)
SECTOR IV - LORRY TIRES (LTs)
SECTOR V - BUS TIRES (BT)
SECTOR VI - OTHER VEHICLES TIRES (OVTs)
SECTOR VIII - INDUSTRIAL RUBBER PRODUCTS
CONTROL PANEL
LORRIES
BUSSES
OTHER VEHICLES
SCRAP TI
INDUSTRI RUBBER
TOTAL WAS RUBBER
PASSANGE CARS


SECTOR VII - TOTAL SCRAP TIRES
SECTOR IX - TOTAL WASTE RUBBER (TWR)
CONTROL PANEL
RETREADING PCTs
EXPORT
PHYSICAL REUSE
ENERGY RECOVERY
MATERIAL RECYCLING
EU legislastion for landfills LANDFILL
scrap tires
total amnt of waste rubber

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