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A management system for end-of-life tyres: A Portuguese case study

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Abstract

The European Union introduced several policy instruments based in the extended producer responsibility (EPR) in order to improve the environmental performance of products and services through their life cycles. In this context, the Portuguese government decided to apply the EPR concept to tyres, and producers were obliged to constitute an end-of-life management system to promote the collection, recycling and reuse of end-of-life (EOL) tyres. This required producers, distributors, recyclers and retreaders to be identified and characterized, and local processing infrastructures to be analyzed. The information was used to design an economically optimised EOL tyre management system while promoting the activity of all EOL operators in order for the imposed collecting and recovery targets to be fulfilled.

This paper discusses the interaction between the different governmental, private and academic institutions for the creation of the integrated management system for EOL tyres, the approach taken, the technical, political and legal aspects underneath them, as well as the environmental consequences induced by the creation of the management system. The results obtained during the first years of operation are reported and show an increase in the collection and recycling of EOL tyres and the consolidation of the collection and processing infrastructures.

1. Introduction

Until the 1980s, economic and political decision makers, such as industries and governments, saw the environment as "business-as-usual" and environmental improvements were focused on the manufacturing processes. During the 1990s, the increasing public perception of the environmental burdens associated with waste generation led to an adverse feeling towards common disposal solutions and resulted in new policies to reduce and divert waste from landfill and incineration towards recycling and reuse. Among these policies, extended producer responsibility (EPR) models contributed to promote reductions in the disposal of consumer wastes (Driedger, 2002).

EPR is based on the polluter-pays principle (PPP), and the objective is to internalise the environmental externalities related to the final disposal of the product, thus providing incentives to prevent the generation of waste, to encourage the eco-design of products and to support recycling and waste management operations. EPR contributed to the shift of the environmental focus from processes to products and from products to services, in a life cycle thinking basis (Ferrão, 2002).

The principle of producer responsibility was mainly implemented in Europe (Lindhqvist, 2000), and was driven by both European and national legislation that promotes the recycling of end-of-life products, as recognized by the European Union (European Commission, 2003). Probably the most famous case of EPR policy is the German Packaging Ordinance, which was successful from an environmental point of view even if its cost efficiency is a topic of much discussion (Hanisch, 2000; European Environmental Agency, 2002). The German experience spread through much of Europe and "green dot" societies for other waste streams emerged.

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In spite of the policy measure's success, it is recognized that the EPR needs to be complemented by other instruments and its effectiveness depends on various factors, namely the administrative implementation costs, post-consumer sorting costs, the type of waste stream, the structure of primary and secondary markets and the public willingness to collaborate in the management system (Organisation for Economic Co-operation and Development, 2001; European Commission, 2003).

Moreover, when recycling is profitable under market conditions and is a well-established activity, it is necessary to have careful planning of the legislation and the implementation process in order to make sure that it does not create heavy distortions in market practices, and, at the same time, that stakeholders do not limit the dynamic nature of the market, which could jeopardize the objectives defined in first place.

This was the context that originated the decree-law 111/2001 in Portugal, which determined the creation of an end-of-life (EOL) tyre management system. The nature of the creation and first achievements are described in this paper.

This paper discusses the environmental rational for the creation of the EOL tyre management system, the procedure adopted in Portugal for setting it up and the results obtained in the first years of experience of the society responsible for the management system (Valorpneu). The interaction between the Portuguese tyre market, the EOL tyre processing infrastructure and the resulting strategy to formulate the EOL management architecture are the main outcomes of this paper.

2. Environmental rationale for an EOL tyre management society

The environmental rationale for processing EOL tyres should be found in analyzing the environmental impacts of tyres through their life cycle and especially in their end-of-life phase.

There are not many tyre life cycle assessments (LCA) available in literature, but one of the most complete was commissioned by the European Association of the Rubber Industry (BLIC) (PRé Consultants B.V., 2001). This study was performed according to ISO standards, which require independent peer review, and considers as its functional unit the average life cycle of an average European car tyre. The tyre chosen was a 195/65R15, whose carbon black version weighs 8.62 kg. To assess the environmental impacts, the main method used in the evaluation was the Eco-indicator 99.

Taking into account the results obtained in the aforementioned study and since the new and used tyre characteristics and average distance travelled considered by Pré are similar to the medium tyre in Portugal, a simple extrapolation based on the weight was made for the medium-size Portuguese passenger and commercial car tyre, to obtain sample results about the environmental impacts of tyres in Portugal for illustrative purposes. Therefore, for the purpose of this paper it was considered that the impacts of different life cycles phases were proportional to tyre weight.

The EOL environmental impacts were obtained taking into account the impacts identified previously for each EOL technology and their relevance in Portugal. Prior to the tyre management system implementation, 29% of the EOL tyres were retreaded, 29% recycled and 10% incinerated (Valorpneu, 2002). The EOL treatment of the remaining 32% is unknown, but because all Portuguese tyre retreaders, recyclers and incinerators were characterized, most were probably landfilled and some were stored or discarded directly into nature, for example in woods and rivers.

To obtain the EOL phase environmental impact sample results, it was considered that the final 32% of tyres were all landfilled. Additionally, in the case of recycling it was considered that the recycler rubber applications were the same as those identified previously.

The resulting life cycle phase contributions to the global environmental impact of the medium-size Portuguese tyre, expressed in Eco-indicator 99 points, are illustrated in Fig. 1. The results show that the use phase is clearly the most relevant for the environmental burdens associated

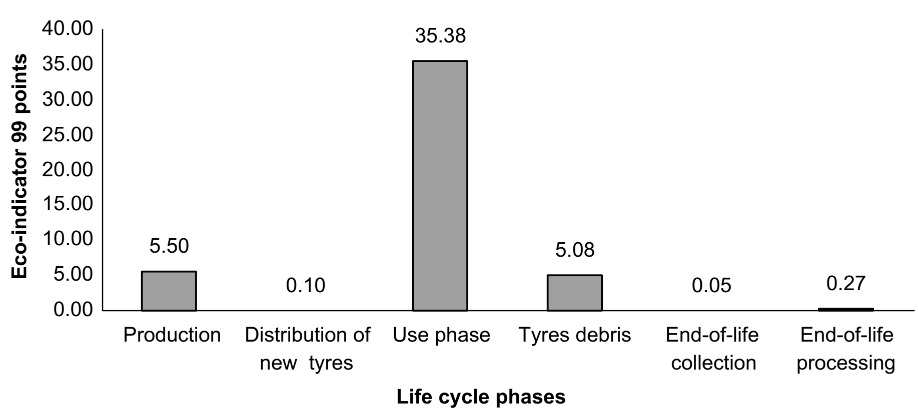

Fig. 1. Contribution of the different life cycle phases on the environmental impact of a medium Portuguese tyre prior to the management system, expressed as weighted Eco-indicator 99 points (adapted from PRé Consultants B.V., 2001).

with the tyres' life cycle, and this is corroborated by other studies (e.g., van Beukering and Janssen, 2000; Nicoletti and Notarnicola, 1999). This is due to the fuel consumption induced by the rolling resistance of the tyres. However, it can be argued that this rolling resistance is an unavoidable tyre characteristic, which guarantees car safety and, as a consequence, it is not of the same nature as the other life cycle phases.

In addition, taking into account the sample results presented in Figs. 1 and 2, one can notice that the end-of-life phase constitutes an important factor to reduce the environmental impacts caused by production, depending on the disposal technologies used to process the tyres. Some considerations about the environmental impacts and benefits of these technologies are discussed in the next paragraphs.

2.1. No end-of-life treatment – discarded stockpiles of tyres

Discarded stockpiles of tyres are not environmentally neutral. For instance, by holding water for long periods of time, and providing sites for mosquito larva development, they are breeding grounds for mosquitoes that are vectors of diseases (Jang et al., 1998). Additionally, discarded tyre stockpiles could create fire hazards. Tyre fires are dangerous because they are difficult to extinguish. Water often increases the production of pyrolytic oil, provides a mode of transportation to carry oils off site and aggravates contamination of soils and water. Air pollutants include dense black smoke, which impairs visibility, and toxic gas emissions. Tyre fire by-products may cause contamination of surface and sub-surface water and soils (Jang et al., 1998).

Discarded tyres also need a very long time for natural degradation due to the cross-linked structure of rubbers and the presence of stabilizers and other additives. Leaching problems occur with metals and some substances that are added to the rubber (Adhikari et al., 2000). Moreover, discarded stockpiles cause visual pollution when disposed in an uncontrolled manner in nature.

2.2. Landfill

The impacts resulting from the tyre landfills are mainly due to the eco-toxicity associated with the leaching of metals (PRé Consultants B.V., 2001), as well as from the leaching of different ingredients such as stabilizers, flame retardants, colorants, and plasticisers, which are mixed with rubber during compounding. After discarding tyres in landfills, there is a probability of leaching small molecular weight additives from the bulk to the surface and from surface to the environment that are not eco-friendly, thus killing advantageous bacteria in the soil (Adhikari et al., 2000). Tyres in landfills also occupy a large space and remain intact for decades. Moreover, when whole tyres are buried they trap air and have a tendency to migrate to the top of the landfills, breaking the sanitary cap and increasing the instability of the sites (van Beukering and Janssen, 2001).

2.3. Energy recovery techniques

Burning of whole discarded tyres obviates the need for expensive shredding operations. However, this kind of burning requires a relatively sophisticated high-temperature combustion facility to keep emissions within environmental limits, and must use equipment capable of handling tyres and feeding them into the combustion chamber (Jang et al., 1998). The use of tyres at existing facilities may require some physical processing or adaptations in the infrastructure. Despite these requirements, converting scrap tyres into fuel is fairly easy because of their high heating value, "clean" combustibility and easy handling (e.g., transportation, storage) (Amari et al., 1999). The incineration processes available include dedicated incineration, incineration in utility and industrial boilers, incineration in cement kilns and pyrolysis.

Tyre pyrolysis produces three principal products: gas, oil and char (Galvagno et al., 2002). The gas and oil have

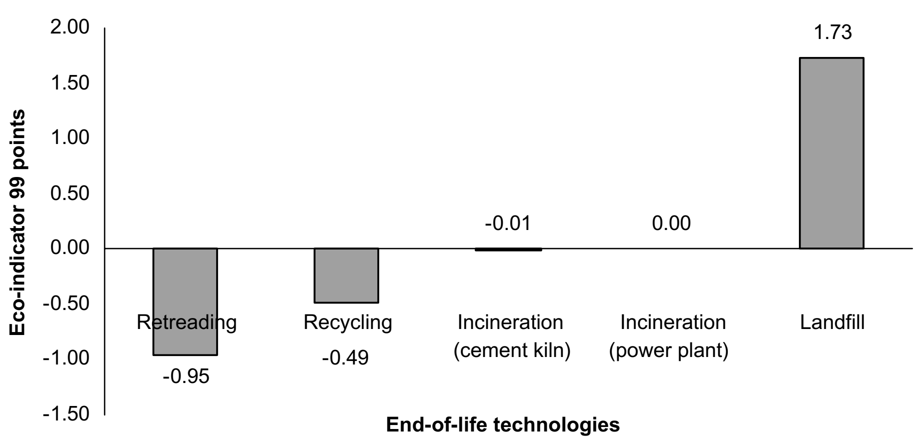

Fig. 2. Contribution of end-of-life technologies for the environmental impact of the end-of-life phase of a medium Portuguese tyre prior to the management system, expressed as weighted Eco-indicator 99 points (adapted from PRé Consultants B.V., 2001).

energy contents similar to conventional products. Char is composed of inorganic materials, such as carbon black, ash, carbonates and silicates. However, due to high costs, tyre pyrolysis projects have not been commercially successful (Jang et al., 1998; Amari et al., 1999).

Depending on the technology used, cement kilns can burn tyres up to 20–25% of their total fuel consumption. A major advantage of using tyres in cement kilns is that the process does not generate solid waste because the ash residues from the combustion are bound to the final product. Sulphur emissions are not a major concern as the sulphur is transformed and bound in gypsum, which is added to the final product (van Beukering and Janssen, 2001).

Amari et al. (1999) estimated that the tyre combustion process recovers 37% of the energy embedded in new manufactured rubber tyres, concluding, by this point of view that it is preferable to recycle rubber rather than to use it as a fuel. Nevertheless, some authors argue that WTE technologies are environmentally preferable to mechanical recycling technologies, mainly due to the avoided use of conventional fuels, as is the case of Corti and Lombardi (2004).

2.4. Recycling

The most frequent recycling activities consist of the use of vulcanized rubber in sport surfaces and floors, as a construction and filling material and as an additive for bitumen in road surfaces. According to PRé Consultants B.V. (2001), the recycling of a tyre has a net environmental benefit because the material recovery avoids the production of certain primary materials and the advantages from material recovery outweigh the impacts of the recycling process itself. Examples of recycling technologies include the traditional tyre mechanical recycling making use of conventional shredding, grinding, and milling process and the more unusual ultrasound mechanical and baro-destructive recycling technologies (Silvestravičiūtė and Karaliūnaitė, 2006).

2.5. Retreading

Retreading offers the most resource-efficient strategy for used tyre recovery, saving both material and energy (Amari et al., 1999). Considerably more energy is required to manufacture a new tyre than to retread a worn tyre. An LCA study commissioned by Continental AG (1999) states that the energy consumption to manufacture a new tyre is 2.3 times superior to a retreaded tyre and the global warming potential of a new tyre is 1.8 times superior to a retreaded tyre.

3. The institutional framework in Portugal

The Portuguese Government assumed that the end-of-life tyres management was a matter of great environmental importance and therefore introduced the decree-law 111/2001 that established the principles and the norms applied to the EOL tyre management, with the objective of waste prevention, enhancement of the collection, retreading and recycling activities, and improvement of the environmental behaviour of tyre stakeholders (MAOT, 2001). Thus, Portugal has become one of the first countries to define this kind of approach for EOL tyres, moving further than the European legal framework, which has only defined the regulatory conditions for tyre landfill (European Union, 1999).

The Portuguese law extends the responsibility of tyre producers to EOL tyres and suggests the constitution of a non-profit society responsible for the management of those tyres. The society, to be licensed for a 5-year period by the Ministry of Cities, Spatial Planning and Environment and the Ministry of Economy, was given the following competences: Suggest the necessary fees to be paid by tyre producers and importers to finance the management system, being the fee subjected to government approval; Set up the EOL tyre collection network and the required logistics, by establishing contracts with distributors, municipal waste systems and others waste operators, setting up the necessary economic compensations; Establish contracts with the retreaders, recyclers and other entities responsible by EOL activities, in order to regulate the society's operating expenses; and Support and guarantee the treatment options of EOL tyres, according to the disposal targets defined by the law.

These disposal targets require that the producers accomplish the following:

- By January 2003: end disposal of EOL tyres according to the national and European legislation (namely the European directive 1999/31/CE); Collect 85% of EOL tyres; Retread 25% of EOL tyres; Recycle and incinerate all recovered tyres that are not retreaded, of which at least 60% must be recycled.
- By January 2007: collect 95% of EOL tyres; Retread 30% of EOL tyres; Recycle and incinerate all recovered tyres that are not retreaded, of which at least 65% must be recycled.

In special cases, in line with the landfill directive and the national law, tyres can be landfilled. These exceptions consist of the huge tyres (over 1400 mm) and the tyres used as engineering material in landfills.

In order to guarantee the economic success of the system, the law imposes that the tyre collection is to be done without any expense to the final consumer. Furthermore, the distributors are obliged to accept EOL tyres when they sell new ones to a consumer.

For EOL tyres producers and owners, the law introduced several technical norms, nevertheless without requiring EOL tyres to be delivered to collecting centers. This decision is left to the EOL owner, in a free market environment.

Table 1
Process that led to the creation of the Valorpneu society and the Portuguese EOL tyre management system

	Producers	Academia	Government
Problem identification	Provide feedback to the government proposals	Support problem characterization	Assessment of the environmental impacts of EOL tyre disposal European and national legal framework assessment Consultation process with stakeholders Decision to legislate
Legal framework			Legal framework definition and law publication
Strategic assessment	Manufacturers gathered in their association to promote a common solution for the EOL management Decision to obtain support from academia Economic and implementation issues analysis Strategy to implement the EOL tyre management system Formal strategy formulation	Academia support for the strategic assessment Develop a model to support strategy definition Model refinement	Technical and policy issues analysis Assessment of the strategy
Implementation process	Legal constitution of the Valorpneu society Development of the collection, logistics and EOL treatment operations network		Valorpneu got its license for EOL management operations Licensing of the collection operators and EOL infrastructures
Solution monitoring	Strategic and implementation corrections	Assessment of results and implementation process	Assessment of goals and economic achievements, on a year-by-year basis

Time ↓

3.1. Procedure adopted to establish the EOL tyre management society

The process that led to the creation of the EOL tyre management society, called Valorpneu, is presented in Table 1. As schematically represented, producers decided to join their efforts and organise their resources in the context of the association that represents them, the Automobile Commerce Association of Portugal (ACAP). ACAP established an internal task force to deal with the problem. To develop the technical and economic aspects of the system and to serve as an independent and facilitator link between different actors, ACAP established a partnership with an academic institution, the Center for Innovation, Technology and Policy Research (IN+), at the Instituto Superior Técnico (Technical University of Lisbon).

It was also decided from the beginning to involve the retreaders and recyclers in the process, so their representative associations (ANIRP – Portuguese Retreaders Association and APIB – Industrial Rubber Association) were also involved. This was done to overcome the sensitive nature of the issue and to ensure a more transparent process for all tyre stakeholders, which have different, and sometimes conflicting, visions and interests.

In this context, producers, distributors, recyclers and retreaders were identified and characterized, the local processing infrastructures were analyzed and the annual production of EOL tyres was calculated. The information gathered was the basis for the development of a strategic approach for the EOL management system, according to three key ideas, in the following order: the environmental and legal target fulfilment; the target fulfilment in an economically reasonable way; and the minimisation of distortions in market practices and stakeholders.

The solution obtained was submitted for approval to the State, through the Portuguese Institute for Waste Affairs (Instituto dos Resíduos-INR), and several pending issues were resolved in an interactive and iterative approach. This process, namely the characterization of the Portuguese market and infrastructures as well the end-of-life tyre management society architecture, is further analyzed in the following paragraphs.

4. Characterization of the Portuguese market and infrastructures

4.1. Annual EOL tyre production

Tyre importers and producers provided the data on their sales to the academic group that conducted the analysis, and then aggregated data were provided to the companies. Together with the data provided by the National Statistical

Institute (INE) and the automotive associations, the annual production of EOL tyres was quantified.

Taking into account the analysis performed, the tyres were classified into 12 tyre categories, as shown in Table 2, plus aviation and bicycle tyres. This classification system was chosen taking into account two factors that affect EOL processing costs, namely the homogeneity in tyre weights and classification used by recyclers, and one factor related to current market practices, namely the classification used by producers. The aviation and bicycle tyres are special classes because bicycle tyres are not usually in the scope of the management system, being collected together with municipal solid waste (MSW), and the aviation tyres have specific processing circuits.

The EOL tyres produced each year were evaluated as the sum of substitution tyres sold in that year, plus the tyres of the vehicles that reached their end-of-life in the same year. The EOL tyre production from 1998 to 2000 for the different tyre categories are quantified in Table 2 (Valorpneu, 2002).

4.2. EOL tyre processing infrastructure characterization

4.2.1. Retreaders

The retreading activity has existed in Portugal for 50 years. It is a mature and developed industry, with a strong presence in the market with commercial and logistic circuits well defined. This occurs especially in the lorry (truck) tyre market, where consumers retread their tyres until the structural limits are reached, in order to reduce costs. The Portuguese retreader industry is also a significant exporter, especially to markets with strong links to Portugal, such as Angola, Mozambique, Brazil and other Latin America countries. At present, there were around 50 retreader companies in Portugal, although the five major companies represent 80% of the market.

The tyre circuits related with retreader activities could generally be characterized by the following: tyres are distributed by retreaders to the tyre distributors or specific agents; and distributors and other agents provide retreaders with previously sorted EOL tyres that are transported back in retreaders' trucks. This could involve a fee paid to the distributors by the retreaders, depending on the market agreements established between them; EOL tyres are inspected and their capability to be retreaded is assessed by the retreaders. Those that cannot be retreaded are returned to the distributors or other agents, or alternatively, the retreaders send them to recycling or incineration, in return for an economic compensation by the distributors. The rejection rate depends on the tyre type and on the retreaders' selection criteria. However, in general, this rate is about 40–50% for passenger tyres and 20–30% for truck tyres.

According to the Portuguese Retreaders Association, in 2000 the amount of tyres retread in Portugal was 21,090 tonnes (Valorpneu, 2002). Of this amount, 25.7% were passenger, 4×4 and commercials tyres; 65.43% were truck tyres; and the remaining were other types of tyres. The amount of passenger tyres retreaded is modest when compared with the truck tyres, mainly because of commercial factors. The passenger tyres more suitable to be retreaded are the high-quality tyres for high-rank vehicles. However, these are also the ones that have less market potential, because a retreaded tyre is perceived to have a lower quality than a new tyre (Used Tyre Working Group, 2000).

4.2.2. Recyclers

There were essentially two tyre recyclers in Portugal, Biosafe and Recipneu. The two companies produce vulcanized rubber granules of various dimensions, being the tyre textile and steel secondary products, which are landfilled and recycled. The rubber granules are mainly exported to other European countries and are sold to be used in floor covering for sports arenas and playgrounds, and for road building, as modified asphalt with rubber, which reduces the surface noise of roads (Ferrer, 1997; Hicks and Epps, 1999; Used Tyre Working Group, 2000). Both recyclers processed a total of 23,600 tonnes of used tyres in 2001 (Valorpneu, 2002).

Table 2
End-of-life tyre production from 1998 to 2000 (excluding tyres that are retreaded)

Tyre categories	Average kg/tyre	1998 tonnes	1999 tonnes	2000 tonnes
Passenger	5.91	15,334	16,444	19,417
4×4 on/off road	13.15	1783	1848	2000
Commercial	10.58	3431	3829	4740
Truck vehicles	52.67	15,606	16,186	19,040
Agriculture (diverse)	12.53	217	317	313
Agriculture (driving wheels)	64.72	2182	1927	1942
Industrial (8–15″)	22.75	885	726	569
Civil Engineering (<12.00–24″)	52.41	32	46	63
Civil Engineering (⩾12.00–24″)	245.35	1461	1327	1472
Motorbikes (>50 cc)	4.10	204	221	307
Motorbikes (<50 cc)	0.84	188	246	168
Total	–	41,323	43,116	50,030

Biosafe uses a dry mechanical grinding process in which the tyre is shredded, the steel removed from the stream by magnetic separation and the textile removed by density. The final product is sorted according to dimensions, which range from 0.5 to 9.5 mm. Recipneu uses a cryogenic process, in which the tyres are shredded into fine granules in a liquid nitrogen environment and at extremely low temperatures, between −55 °C/−60 °C. The product has better flow characteristics than mechanically shredded rubber (Adhikari et al., 2000). The steel is removed by magnetic separation and the textile removed by aspiration. Both recyclers receive used tyres in return for economic compensation. The amount depends on the recycler and on the tyre type; it ranged from 35 to 70 EUR/tonne before the constitution of the new EOL tyre management system.

4.2.3. Incinerators

In 2003, there was only one tyre incinerator in Portugal, CMP, which processes tyres in a rotary cement kiln as a complementary energy source, benefiting from its relatively high heat content (around 33 MJ/kg), which is similar to coal (Ferrer, 1997).

CMP has an incineration capacity of 16,000 tonnes/year; however, due to cement production considerations it utilized only half of its installed capacity (Valorpneu, 2002). The company accepted only intact EOL tyres, which have a diameter above 385 mm and below 1220 mm, because of limitations imposed by the automatic transportation system and kiln entry. CMP, like the Portuguese recyclers, collected a fee to accept the used tyres, which was 27.7 EUR/ per tonne before the EOL system implementation.

5. The EOL tyre management society architecture

As discussed in Spicer and Johnson (2004), several models were available for EOL product management:

- Non-EPR mode, in which the products are recycled or remanufactured, only when profitable. In this system, the economic burden is supported by the consumer or government.
- OEM takeback, in which original equipment manufacturers themselves take physical and economic responsibility for the products that they have manufactured. Each company manages its own de-manufacturing facilities, in which its products are disassembled for remanufacturing, recycling or other environmentally responsible outcomes.
- Pooled takeback, in which physical and economic responsibility for products is assumed by a consortia of manufacturers, usually grouped by product category. These consortia are a form of producer responsibility organization (PRO). The PRO would manage de-manufacturing facilities where category products would be retired.
- Third-party takeback in which private companies assume EOL responsibility for products, on behalf of original equipment manufacturers (OEM). An OEM would pay a fee to a product responsibility provider (PRP) that would then promise to ensure that the manufacturer's products are retired in a way that is environmentally responsible and compliant with EPR legislation.

Conceptually, in Portugal, the EOL strategic approach was to promote the economic viability of the entities that contribute to the fulfilment of the environmental targets required by the law, and to cause the minimum possible perturbation in the existent market mechanisms that are well established. In this context, after the producers, distributors, recyclers and retreaders were identified and characterized in terms of capacity and processing fees and the local processing infrastructures analyzed, the national system was defined, the fees to finance the system were set and the society for EOL tyre management, Valorpneu, was created, within a mixed model of the pooled takeback system and the profit-oriented model if we adopt the nomenclature suggested by Spicer and Johnson (2004).

A problem that arises in this type of model is that it does not promote eco-design because the tyres from different companies are not differentiated in terms of cost allocation. However, in this product and because almost all tyres are produced by big companies and imported, even a Portuguese cost system rewarding eco-design of tyres would have little influence in tyre design. Also, the main driver for tyre eco-design is the tyre use phase, namely in terms of durability and energy consumption, thus in terms of CO_2 emissions, and this is one of the main drivers for tyre innovation.

The retreading activity is a well-established sector in Portugal, with well-defined commercial and logistics circuits, and the retreading rate was already superior to the target establish by the law. The main issue here was not to distort this market. As a consequence, retreaders are only required to provide retreading data to the system management, and their procedures are not included in the economics and logistics of the system.

The Valorpneu scope of activity is presented in Fig. 3. Valorpneu was created as a non-profit organization in which the stakeholders are the producers, via ACAP, with 60% of the shares, the retreaders, via ANIRP, with 20% of the shares and the rubber industrials, via APIB, with the remaining 20% of the shares.

In this context, Valorpneu manages the EOL system, as follows:

The producers/distributors/importers pay a fee for each tyre put in the market to Valorpneu (producer's fee, as presented in Table 3). The fees were calculated taking into account the foreseeable costs for the EOL tyre system management, in a 5-year period, using a detailed and comprehensive technical-economic model built specifically for that purpose. The financial requirements for each EOL operation were considered (storage and sorting, transportation and recovery), including the costs related with human

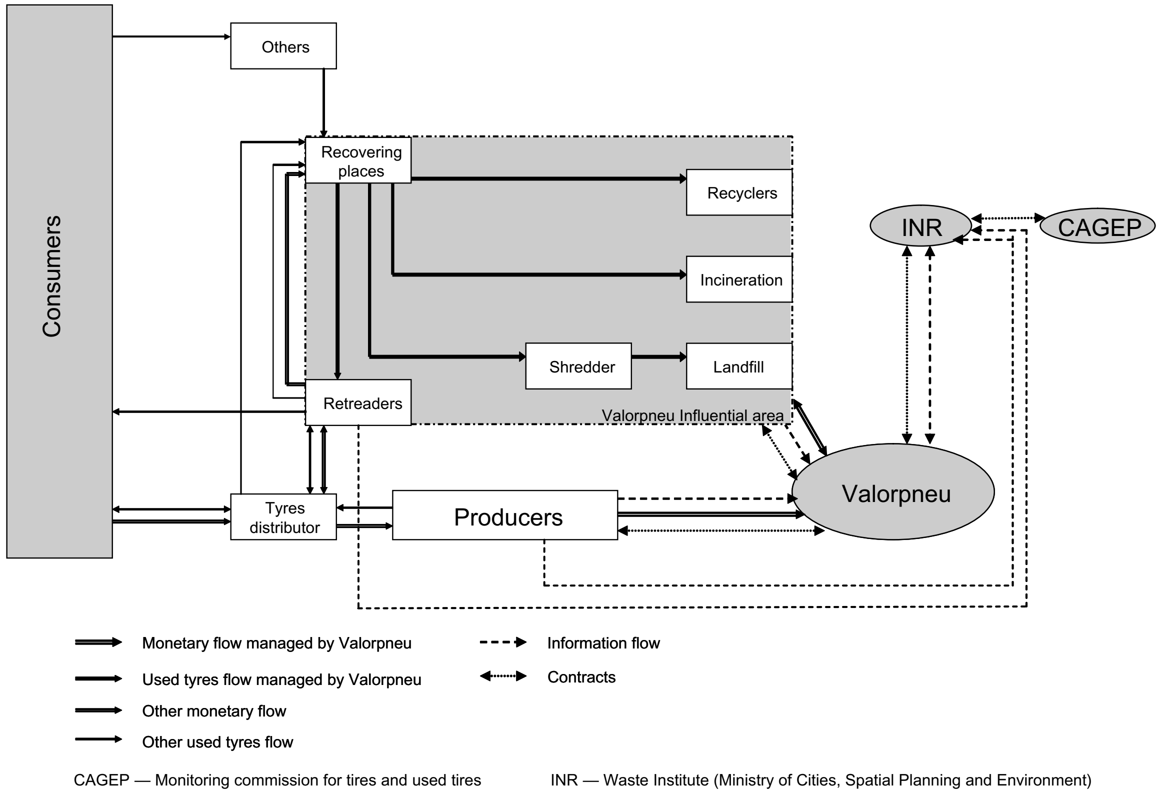

Fig. 3. Portuguese integrated management system for EOL tyres.

Table 3
Producer fee per tyre

Tyre categories	Euros/tyre
Passenger	0.80
4 × 4 on/off road	1.79
Commercial	1.44
Truck vehicles	7.18
Agriculture (diverse)	1.71
Agriculture (driving wheels)	8.82
Industrial (8–15″)	3.10
Massive tyres	3.72
Civil Engineering (<12.00–24″)	7.14
Civil Engineering (⩾12.00–24″)	40.13
Motorbikes (>50 cc)	0.56
Motorbikes (<50 cc)	0.11
Aviation	0.80
Bicycles	–

resources, administrative tasks, investment depreciation, marketing and R&D projects promotion, taking into account also the characteristics of each tyre category defined. The necessary revenues were therefore calculated and translated into producer fees by category, considering a scenario for new tyres sales in the same period.

Tyre collection centers (which have contracts with Valorpneu) were especially created to accept and temporarily accumulate EOL tyres disposed by professional, private and public entities. EOL tyres owners, in turn, are physically and financially responsible for the transportation of EOL tyres to the centers and this activity is performed by private operators. The collection centers are storage facility providers and after a certain amount of tyres are stored, Valorpneu can move them to recyclers or for energy recovery. In return Valorpneu pays a fee of 23 EUR/tonne to the collection centers (reference of 2005), rewarding the collection and storage service they provide. The payment in only made after EOL tyres left the facility for recycling or energy recovery.

Anyone could deposit their end-of-life tyres at the collection centers, without any fee.

Besides the traditional direct collection of EOL tyres at the tyre distributors (that are requested to accept from the consumer EOL tyres on a “old” for “new” basis), retreaders can also acquire used tyres that reach the collection centers, by paying the same fee that Valorpneu pays for every tyre that leaves the collection center for recycling or incineration. This significantly increased the number of EOL tyres that are made available to retreaders.

The recyclers and the incinerators process the used tyres received from Valorpneu, in return for financial compensation. The amount of the “gate fee” paid by Valorpneu is variable and does not only depend on the operation in question, but also on market conditions negotiated by Valorpneu with each EOL recovery company. The average value in 2004 was 60 EUR/tonne of tyre processed (Valorpneu, 2005).

Disposal in the used-tyre landfill is the least preferable method, and occurs only in the particular situation for which this option is possible. The average value paid in 2004 was 41 EUR/tonne (Valorpneu, 2005).

The transport of tyres between the collection centers and the recyclers, incinerators and landfills is controlled and financed by Valorpneu. The transport to the retreading facilities is the responsibility of the respective retreading company. The average transport cost in 2004 was 29 EUR/tonne (Valorpneu, 2005).

6. Results obtained by Valorpneu

Valorpneu started its operation in February 2003, with a network of 11 collection centers. At the end of the year 2005, the number of collection centers had increased to 34, significantly reducing the travel distance necessary to distributors and other agents to dispose their end-of-life tyres. Distributors and other agents maintain the possibility of carrying EOL tyres directly to retreaders, recyclers or incinerators, but in that case, they must bear the costs for the EOL operation, when applied.

The overall results obtained by Valorpneu during its three year of activity are presented in Table 4.

From analyzing Table 4 and Fig. 4, one can notice that the EOL production figures were higher than the number of new tyres sold in 2003, 2004 and 2005. This is due to a conjugation of factors. For instance, there was an appreciable reduction in the number of tyres sold in Portugal in recent years, caused especially by a significant reduction in the number of new vehicles sold. On the other hand, a tyre reaches its end-of-life in general after 3 or 4 years of use, so the EOL tyre production in recent years mainly resulted from tyres sold near the peak in new tyre sales. It is clear that the dynamics of this system are extremely important in order to project the EOL production in the future and thus the economic costs associated with EOL processing. Therefore, this must be taken into account whenever an EOL management system is to be designed.

Valorpneu collected 59,069 tonnes of tyres in 2003. The collection rate achieved was 86%, superior to the target defined. The retreading rate was 27%, and 75% of the tyres collected that were not retreaded were recycled. Thus, the targets imposed by the law were fulfilled in the first year. In the subsequent years, Valorpneu has increased its results, mainly by achieving a higher rate of collection and recycling.

Compared with the situation prior to the management society, one can notice that there was an increase in the amount of EOL tyres recycled. In terms of total recycling rate, compared with the total EOL tyre production, there was an increase from 29% to 49%, and the incineration rate doubled from 10% to 20% (see Table 5). This was done mainly by diverting to recycling and incineration the fraction that was previously landfilled, stored and disposed in the nature in an uncontrolled manner. If we considered the Portuguese sample results based on the Eco-indicator 99, this would lead to the fact that the management society contributed to a reduction in the overall tyre life cycle environmental impacts, because the EOL phase

Table 4
Valorpneu results in the first three years of activity

	In tonnes		
	2003	2004	2005
Tyres sold (with fee payment)	61,038	73,668	72,614
EOL tyre production	68,353	78,801	79,198
EOL tyres collected by the Management System	59,069	76,681	77,828
EOL tyres retreaded	18,429	20,538	19,808
EOL tyres reuse (except retreading)	–	1588	1623
EOL tyres recycled	30,633	33,470	38,641
EOL tyres incinerated in cement kilns	9287	16,554	16,165
Tyres to landfill	720	4531	1591
Historical waste	1905	14,406	6771
Historical waste incinerated in cement kilns	1905	13,532	6382
Historical waste landfilled	–	874	389
Total waste processed by Valorpneu	60,974	91,087	84,599

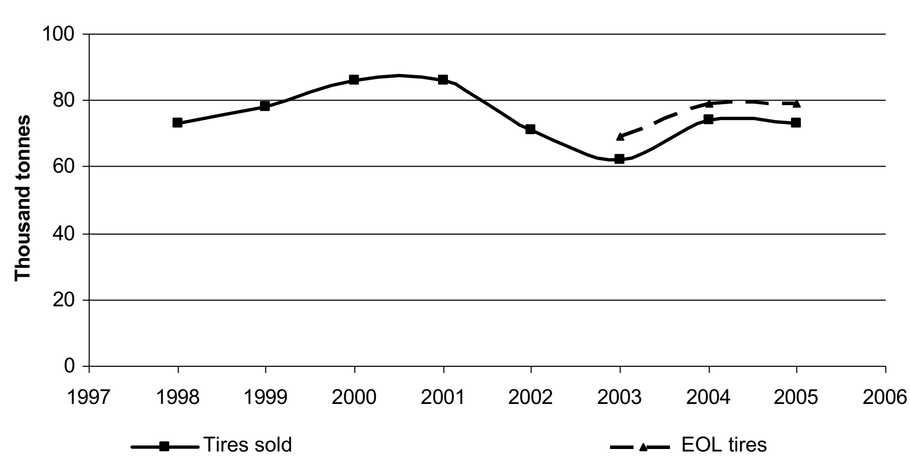

Fig. 4. Evolution of the tyres sold and the EOL tyre production.

Table 5
End-of-life options before and after the Valorpneu society

	2000		2003		2004		2005	
	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%
Retreading	21,091	29	18,429	27	20,538	26	19,808	25
Reuse (excep. Retreading)	–	–	0	0	1588	2	1623	2
Recycling	216	29	30,633	45	3347	42	38,641	49
Incineration (cement kilns)	7634	10	9287	14	16,554	21	16,165	20
Landfill	–	–	0.720	1	4531	6	1591	2
Unknown	23,441	32	9284[a]	14	2.12[a]	3	1.37[a]	2
Total	73,766	100	68,353	100	78,801	100	79,198	100

[a] Not collected by Valorpneu.

contribution changed from (+)0.27 Eco-indicator 99 points, before the system implementation to (−)1.64 Eco-indicator 99 points, taking into account the last EOL results.

The increase in the recycling rate resulted in more than 17,000 tonnes of tyres recycled, despite the fact that the total EOL production was slightly reduced from 2000 to 2003, due to the economic recession in Portugal. The retreading option remained quite constant, comparing the situation before and after the implementation of the new system, because this option is almost used at full capacity, taking into account the technical and market characteristics of new and EOL tyres produced. In fact, according to the ETRMA data for 2005, the retreading rate in Portugal is the highest in the EU-15 space, two times higher than the European average, which is 12% (ETRMA, 2006).

Looking at these results, one can notice that the end-of-life options changed with Valorpneu, resulting in a very significant increase in the recycling and incineration options, thus contributing to the reduction in the environmental impact of the tyre life cycle, as explained before. Another relevant contribution of the Valorpneu society was the stability that it has brought to recyclers. Before the creation of Valorpneu, the recyclers were in bad financial shape, facing imminent closings. With the management society, the increase in the EOL treatment fee ensured an improvement in their economic performance and, thus, an increase in the stability of the EOL management system, allowing for the fulfilment of the collection and recycling goals. Likewise, the producer fees have remained constant since the management system implementation, in spite of an increase in the recovery costs, mainly due to efficiency gains obtained by Valorpneu. On the other hand, the use of a "visible fee" system has not clearly resulted in a direct increase in tyre prices paid by final consumers.

Additionally, Valorpneu has assumed the responsibility for the EOL tyre stockpiles that were accumulated in the country during previous years, which had no owners and were abandoned in the environment, causing environmental problems. This historical waste, i.e., the batch of existing and unprocessed EOL tyres, which was estimated at more than 30,000 tonnes, has mainly been incinerated and the process is expected to be completed in 2007. Valorpneu has also promoted several environmental and security procedures for the different EOL tyre operators to ensure the correct collection, transportation and processing of EOL tyres.

7. Conclusions

The environmental rationale for processing EOL tyres is based on the analysis of the environmental impacts of tyres through their life cycle and especially in their end-of-life phase. In this context, the Portuguese government anticipated any EU directives, by creating a legal framework for extending the responsibility of tyre producers and importers over EOL tyres. Landfill and incineration without energy recovery were severely limited and collection, recycling and reuse were strongly promoted. Producers were obliged to constitute an end-of-life management system.

This paper discussed the interaction between the different governmental, private and academic institutions for the creation of the integrated management system for EOL tyres; the approach taken; the technical, political and legal aspects underneath them; and the environmental consequences induced by the creation of the management society, Valorpneu. It was shown that the EOL tyre dynamics are extremely important, in order to foresee the EOL production in the future, and, as a consequence, the costs associated with tyre EOL processing.

The results obtained during the first year of operation of the system by Valorpneu were reported, and revealed an increase in the EOL tyre collection, and the consolidation of the EOL tyre collection and processing infrastructures. Valorpneu has managed to fulfil its collection, retreading and recycling targets in the first years and ensured financial and organizational stability in the Portuguese end-of-life market and infrastructure, particularly in relation to recyclers.

Overall, it can be concluded that the EPR policy triggered by the Portuguese law on EOL tyres, together with the creation of Valorpneu, have led to a significant improvement of the environmental performance of tyre end-of-life processing practices, and thus contributed to reduce the environmental impact of tyres in Portugal.

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