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FOSTERING ECO-INNOVATION: WASTE TYRE RUBBER AND CIRCULAR ECONOMY IN CROATIA

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ABSTRACT

The aim of this article has been to provide an insight into Croatian waste tyres market, which is assumed to be the source of significant eco-innovation. At the outset, the analysis of relevant literature has been done regarding the circular economy and eco-innovations. The empirical part of the study used the Strength-Weaknesses-Opportunities-Threats method in order to determine the perspective of the main market stakeholders. In the course of the SWOT method conducting, an in-depth interview was organized with managers of the only authorized mechanical recycling company in Croatia and an on-line questionnaire was used to learn about thinking and attitudes of other ELT market stakeholders in Croatia – representatives of the Ministry of Environmental Protection and Energy, Environmental Protection and Energy Efficiency Fund, Agency for the Environment and the Nature, authorized ELT collectors, Croatian scholars involved in previous waste rubber scientific studies as well as representatives of companies either using or selling rubber recyclate. Additionally, comparison to the European context has been conducted. Findings suggest that Croatian legislation and practice follow European trends: collection rate of waste tyres is near 100 %, and the total collected amount is being recycled – 83 % as the secondary raw material and 17 % as energy recovery. However, situational analysis detected that underdeveloped industrial production hinders seizing the full potential of produced raw material, thus missing the opportunity of generating the higher added value for the domestic economy. Consequently, Croatia's Eco Innovation Index was by 28 % lower than the EU average in 2017.

KEY WORDS

waste tyre rubber, eco-innovation, circular economy, Croatia

CLASSIFICATION

JEL: O52, P27, Q56

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INTRODUCTION

Circular economy initiatives aim to keep the value of products and materials as long as possible in the economy while minimizing the generation of the waste. The ultimate goal of promoting a circular economy is the decoupling of environmental pressure from economic growth [1]. In the same time, conceptualizing on circular economy and striving to implement different initiatives, represents a major contribution to the development of a sustainable economy, in which resources are being exploited efficiently, and new competitive advantages are being created.

One of the significant circular economy initiatives, i.e., opportunities is the use of waste tyres, also called the end-of-life tyres (ELT). But, this opportunity is not straightforward, so although it is intensively researched, especially during the last five years [2], exploitation of innovative ideas and solutions is still limited with obstacles to bring innovation into commercial success [3]. However, ELT does represent an eco-innovation source, important in terms of business as well as for policy development.

Literature research conducted for the purpose of this study has indicated that there are no recent scientific papers regarding available quantities of ELT rubber residues as well as their management system in Croatia. Beside scientific sources, not even official European records contain data on ELT resources availability in Croatia nor studies regarding their potentials (ETRMA). Additionally, the environmental and economic sustainability of circular economy framework is very site specific, so beside the type of the material being researched, it depends on several other factors like transport distances, economic and political context [2]. Therefore, research within particular countries is needed, as it builds to the existing body of knowledge. Therefore, the intent of the study has been to fulfil that research gap, providing the answer to the initial research question: What are the characteristics and potentials of Croatian waste tyres market?

The stated research question has led to the following two research propositions.

> **RP1**: Although smaller, Croatian waste tyres market is in compliance with characteristics of the European waste tyres market in terms of legislation, collection rate, and recovery structure.
>
> **RP2**: Waste tyre market is a significant source of eco-innovations in Croatia since it provides opportunities for recycling, re-use, and new business models development, thus contributing to circular economy initiatives.

The propostitions has been investigated using qualitative research methods, and the article itself has been organized in six sections. Immediately after the Introduction, a section providing the literature review is being presented. It has been divided into three subsections, in order to provide necesarry framework regarding legislation and financing models, eco-innovations as well as recycling methods and possible uses of used tyres. The third section, called Data and methods presents details regarding the sample characteristics and scientific methods applied. The fourth section displays the empirical part of the Croatian waste tyre market study whilst the fifth section reflects on the results. The final section brings concluding remarks. Important acknowledgement, as well as references used, are given at the very end of the manuscript.

This article results from the study which is part of the research being done in the course of the scientific project called Development of Reinforced Concrete Elements and Systems with Waste Tyre Powder, financed by Croatian Science Foundation. It belongs to the first research

phase, putting emphasis on the analysis of the rubber compound of ELT and its potentials, especially in terms of its availability in the Republic of Croatia, ELT market functioning and the related situation in that country.

LITERATURE REVIEW

REGULATION AND FINANCING OF TYRE WASTE

The global population is becoming increasingly aware of the scarceness of resources, but at the same time, we are facing the growth of the population and its ever greater demand for access to wellbeing. The only possible response to such a situation is the attempt of improving the efficiency and effectiveness of resources use, including their re-use. Consequently, resource scarcity is the driver behind the circular economy. The recovery of materials and energy can add significant new value streams and improve cost recovery [4].

The circular economy is an economic model that encourages the so called 3R principle: reduce, reuse, and recycle. As such, circular economy model, in fact, implies a mind-set change that considers waste as a potentially useful resource and not as a problem to manage and dispose of in landfills, as in linear economy [5].

Throughout history, there have always been attempts of re-use, but from the time of the industrial revolution, after men had discovered how to produce quickly and cheaply and we evolved into an increasingly throwaway society, the concept of the circular economy became more important than ever. It became an alternative to the dominant economic development model, so called "take, make and dispose of" [6].

In December 2015 European Commission adopted the ambitious Circular Economy Package, including legislative proposals on waste, to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs. Later, as part of its continuous effort to transform Europe's economy into a more sustainable one, the Circular Economy Action Plan was introduced, establishing a specific programme of action, with measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials [7].

The proposed measures have aimed to contribute to "closing the loop" of product lifecycles through greater recycling and re-use, thus generating benefits for both the environment and the economy. By promoting the adoption of closing-the-loop production patterns within an economic system, a circular economy aims to increase the efficiency of resource use, with special focus on urban and industrial waste, to achieve a better balance between economy, environment, and society [1].

Regarding waste tyres, it should be emphasized that, if discarded into the environment, ELT become a problematic waste due to their volume and durability. They are very slowly degradated under the influence of solar radiation, and the products of this degradation gradually pollute soil and underground water. Additionally, thrown ELT are an ideal habitat for mosquitos and rodent reproduction [8]. In consequence, collection and recycling of waste tyres are extremely important in order to prevent their harmful impact on human health and the environment, but also in order to use them as an economically valuable resource.

Therefore, two significant directives have been introduced: the Waste Directive [9], setting the basic concepts related to waste management, such as recycling and recovery as well as the Landfill Directive [10], which outlawed ELT as well as shredded tyres to be deposited on landfills. Additional legislation has driven the sector towards recovery and recycling, with the collection rates near 100 % in much of Europe.

However, the EU's official opinion is that Croatia still needs to prioritise its national strategies. The scope of policy measures that support eco-innovations for the circular economy needs to be both more comprehensive and more focused in order to cover all relevant segments of the economy and regulations, such as regulatory instruments, economic instruments, R&D funding as well as information, networking support and voluntary measures [11; p.15].

Pragmatically, the starting point for ensuring efficient recycling and circular economy in general, as well as in the context of end-of-life tyres, is every government's responsibility at aligning policies and creating an efficient legal framework. Today, there are three different ELT management schemes in Europe [3].

The first scheme is extended producer responsibility (EPR), in which the original manufacturer has a duty of care to ensure that the waste from the products it has created is disposed of responsibly, in an environment sound manner. This makes the producer (defined as a manufacturer or an importer) responsible for the waste that the consumer generates. These companies are mandated by law to collect and organize the treatment of an equivalent amount of the volumes of tyres sold on the same year. The process is financed through an environmental contribution charged by ELT companies to tyre manufacturers and importers. Furthermore, the fee is passed on by those producers to the end users, clearly indicated on the invoices, ensuring so transparency of costs. Clear and reliable traceability is additionally fostered through a reporting obligation of the ELT management companies towards the national authorities. Currently, EPR is the most widespread system in Europe with 21 EU member countries as well as Norway and Turkey practicing it.

The second scheme is a liberal system, also called the free market system, represents the legislation that sets the objectives to be met but does not designate those responsible. In this way, all the subjects of the recovery chain contract under free market conditions, meaning that their voluntary cooperation is the platform for promoting the best practice and acting in compliance with the legislation. Such system is present in Austria, Switzerland, Germany, and the UK, wherein the UK operates a "managed free market," having the ELT collectors and treatment operators obligatory to report to national authorities.

The third scheme is a tax system, which represents a system in which a government is responsible for the management of ELT. It is financed by a tax levied on tyre producers and subsequently passed on to the consumer. The tax system is applied in Denmark and Croatia. Croatian market shall be analysed in more details in this article.

ECO-INNOVATION IN THE CONTEXT OF CIRCULAR ECONOMY

According to the Oslo manual [12; p.70], the international reference guide for collecting and using data on innovation, there are four basic types of innovation: (i) product innovation – a good or service that is new or significantly improved. This includes significant improvements in technical specifications, components, and materials, software in the product, user friendliness, or other functional characteristics, (ii) process innovation – a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment, and/or software, (iii) marketing innovation – a new marketing method involving significant changes in product design or packaging, product placement, product promotion, or pricing, and (iv) organisational innovation – a new organisational method in business practices, workplace organisation, or external relations.

There are also other typologies of innovation. Authors of this article find interesting the stand of Eco-Innovation Observatory (EIO), a platform for the structured collection and analysis of an extensive range of eco-innovation information, gathered from across the European Union and key economic regions around the globe. It adapts the above stated types and emphasizes

so called eco – innovations, as innovations that take place and have effects in different dimensions (types) [13; p.9].

As reported by EIO, in order to foster the resource-efficient green economy and sustainable growth, economic growth must be decoupled from primary resource consumption by finding the growth opportunities in resource efficiency, recycling, re-use and other new business models [14; p.6].

This is where eco-innovations step in, since they have been defined as any new or significantly improved product (goods or services), process, organisational change or marketing solution that reduces the use of natural resources (including materials, energy, water, and land) and decreases the release of harmful substances across life-cycle [13; p.8]. As such, eco-innovations refer to all forms of innovation – technological and non-technological, new products and services and new business practices – that create business opportunities and benefit the environment by preventing or reducing their impact, or by optimising the use of resources [15].

Factors like external government pressures, financial subsidies, technological capabilities, environmental, organisational capabilities, a market-based instrument, competitive pressures, and demand for greener products can act as drivers for the development of eco-innovation. In Croatia, external government pressures and financial subsidies have been recognised as the main incentivising factors for the expansion of the circular economy and eco-innovation [11].

But there are also more or less influential barriers to circular economy and eco-innovations. Generally, cultural, technological, market, and regulatory barriers exist. To be more specific, several issues have been listed in Croatia's Eco-innovation Profile [11; p.12] as the biggest barriers: (i) limited Green Public Procurement (GPP) funding/support, (ii) a lack of awareness and/or willingness to engage in circular economy principles from the general population, (iii) Croatia's territorial disparity (e.g., number of islands shape of the country) and territorial organisation (number of municipalities/counties), (iv) the significant lack of investments in R&D. In 2016, R&D expenditure in Croatia represented only 0,84 % of GDP; and (v) the lack of quality solutions and examples of good practices for connecting the private and public sector. Croatia is still insufficient when it comes to investment in recycling and recovery infrastructure, as well as circular product eco-design and 3R production (re-use, recycle, and repair).

Since the focus of this article is on ELT, the empirical part of this research pays attention primarily to the last listed barrier, although others have been detected through SWOT analysis as well.

USED TYRES RECYCLING METHODS AND POSSIBLE USES

The discourse on ELT as raw material should mention that tyres are made from several components, being rubber, steel, and textile. Rubber makes up some 70-80 % of the tyre mass and the rest are steel belts and textile overlays [16]. Such a compound makes tyres a demanding resource, due to their highly complex structure, the diverse composition of the raw material, and the structure of the rubber from which the tyre was made [8]. Nevertheless, efficient separation of components and recycling is feasible due to modern technology. Their recycling requires a high time and energy outlay and is based solely on the mechanical, thermal or chemical destruction of the rubber product; recovery of the raw materials used to produce them is impossible [17].

Feasibility of recycling in the ELT market sector is based on two main facts: used tyres are clearly identifiable products, and their collection is distinct from all other waste streams. Additionally, even regular maintenance of tyres during their initial use phase is in compliance

with the circular economy, by extending their life span and mitigating the demand on natural resources. The relevant literature [8] however states that, from the aspect of circular economy concerning used tyres management, there are several options that are being practiced: retreading, energy recovery, pyrolysis, product recycling, and material recycling. The main difference among those procedures is that retreading happens in the usage phase of tyres whilst all the others are applied on ELT.

Retreading is described as a process for extending the lifetime of tyres based on the reconstruction of the tread pattern of the used tyre by removing the worn tread and placing a new layer of a rubber compound [18, 19].

Regarding energy recovery, it should be said that it is a widely practiced procedure because the calorific value of used tyres is higher than many others, especially coal's, which makes them competitive with other energy sources. Such tyre derived fuel is mainly used in the cement industry, which uses them as an alternative fuel co-combusted with coal [20]. Additionally, economic aspects of energy recovery from used tyres are very appealing, too [21].

The pyrolysis of tyres, meaning heating them to temperatures of 400-700 °C, in the absence of oxygen, yields a series of valuable chemical compounds in solid, liquid or gaseous form, which after suitable processing could be used in the petrochemical, energy or iron and steel industries [22]. However, equipment and its servicing needed for the process generates high costs, resulting in uncompetitive prices of created products. Therefore, the pyrolysis of used tyres is, in fact, very rarely used on an industrial scale [8].

Product recycling is based on the recycling of entire used tyres, in their original form, without any physical or chemical treatment. As such, it is rarely used and is of marginal importance for the circular economy, but there are examples of waste tyres being used as protective barriers along roads or waterfront banks, like fenders, as insulation in building foundations, etc [8].

Finally, material recycling is the most common means of managing used tyres, and it decomposes ELT into their constituent elements: steel, textile, and rubber. Steel component from all tyres is of extremely high quality, so there is a demand for that feedstock for the production of new steel by the European steel industry. As for the textile, there has always been a question of usage. Unlike the other two components, production of the clean textile from ELT remains a challenge since it is usually contaminated with rubber fragments. In the same time, it's separation is a hazard in the workplace as it creates dust and fibres on and in the machinery and in the atmosphere. However, the textile component is being used for new insulation products, as a source of energy, and experimentally as reinforcement in concrete [3].

Material recycling of the rubber ELT component is realized as mechanical grinding of tyres, which creates rubber materials of different degrees of fragmentation, or as devulcanization, which produces rubber regenerates [23]. Rubber regeneration play an important role in the rubber industry, while products of mechanical grinding have many different applications, mostly depending on their size. In the EU, used tyres material recycling market has been standardized by the European Committee for Standardization (CEN) [24], by classification of those products after their size, as presented in Table 1.

Table 1. Types of rubber products by standardized size. Source: authors' work, based on [24].

Type of recyclate	**Size, mm**
Cut tyres	> 300
Shreds	20 – 400
Chips	10 – 50
Rubber granulate	0,8 – 20
Rubber dust	< 0,8

Different stages of size reduction will create an end product with different properties, therefore recycled rubber is already being used in different industries, for different purposes: in rubberized asphalt [25], in production of athletic tracks as well as in noise reduction and anti-vibration solutions. But the most obvious market that is sure to grow is different uses of tyre derived rubber in concrete [3].

The size of the European concrete market is huge – its volume is in excess of 39,4 Mm^3 of concrete being produced in the 16 European countries represented at the European Ready Mixed Concrete Organization [26] plus Norway, Switzerland, Israel, and Turkey. Both research and commercial applications of rubber in concrete already exist. So far, the aim of rubber incorporation has been mostly to lighten the concrete and increase its performances, primarily increased resistance to cracking and the capacity for deformation. Adding rubber from ELT provides the concrete with increased durability and a greater aptitude for absorbing mechanical vibrations [27-29]. Due to good thermo-insulating and waterproof properties together with its resistance to environmental factors, rubber recyclate in concrete is ideal as filling material in tunnels and underground passages as well as material for drainage layers of embankments and drainage ditches [8].

However, the commercial use of recycled material from ELT is still threatened by the idea that goods produced from waste will be of lesser quality, or they will be cheaper. Neither is necessarily true, though both can be correct. Yet, the implementation of the circular economy still seems in the early stages, mainly focused on recycling rather than reuse [1].

METHODOLOGY

A literature review of a circular economy approach to the construction sector done by Ghisellini, Ripa and Ulgiati [2] suggested that the life cycle assessment method has been the most often used scientific form, applied in 40 % of case studies. It is followed by the literature research as the primary method in 19 % of studies, while other methods like financial analysis, questionnaire surveys, multi-criteria analysis, and others are used in the rest of the cases.

The study presented in this article is considered a preliminary investigation of the Croatian ELT market. In regard to methodology, it combined relevant literature research in its first phase with situational analysis using the SWOT method after that.

In the course of the literature research presented in the previous section, the content analysis method was applied to learn on circular economy and innovation principles as well as state of the art studies in the field. Synthesis method was used to summarize the previous findings, in order to notice relevant causalities and implications that might be important for both scholars and professionals.

The empirical part of the research aimed to perform the situational analysis identifying strengths, weaknesses, opportunities, and threats of Croatian ELT market. SWOT method statements have been constructed drawing on the survey responses gathered from interviews and an on-line questionnaire.

In-Depth interviews were conducted with managers of the only authorized mechanical recycling company in Croatia. Interviews have been semi-structured, administered separately with both technical manager and sales manager of the company. Interviews have been conducted in person, at the interviewees' headquarters in Varaždin, Croatia. Only questions regarding annualy processed quantites of ELT uses of recyclate practiced as well as realized income have been pre-determined. Additional questions have been spontaneously asked during interviews to clarify and/or further expand issues regarding problems and potentials

present at the Croatian ELT market. Interview with the technical manager has been conducted at first in his office, and then continued in the form of a recycling plant tour, which gave the authors a chance of insigth into the applied technology, too.

An anonimuous on-line questionnaire was used to grasp the attitudes of other ELT market stakeholders in Croatia – representatives of the Ministry of Environmental Protection and Energy, Environmental Protection and Energy Efficiency Fund, Agency for the Environment and the Nature, authorized ELT collectors, Croatian scholars involved in previous and current waste rubber scientific studies as well as representatives of a company using and selling rubber recyclate. Since there have been only 3 scientific projects in Croatia regarding waste tyres, there are in total 15 companies which are authorized as collectors of ELT [30] and there is only one company that is a significant user and seller of rubber recyclate, the link to the on-line questionnaire has been e-mailed to heads of each of the projects, i.e. to a chosen manager in all listed public institutions and all mentioned companies. This resulted in the size of the sample measured as 22 possible responses. Due to the expertise of all respondents, the questionnaire consisted of open-ended questions regarding strenghts, weaknesess, opportunities, and threats of the waste tyre market in Croatia. The questionnaire responses have been automatically gathered in an on-line data base. In total, 14 questionnaires have been completed: all questioned public institutions and scientists, the recyclate using the company and 7 collecting companies responded.

Inductive and deductive reasoning principles have been applied in order to draw conclusions from the conducted survey and to invesetigate research propositions. Details regarding the empirical part of the study and discussion on results are presented in subsequent sections.

RESULTS

WASTE TYRES MARKET IN EUROPE

Significance of the circular tyre economy could be backed up by up to date waste tyres statistics because over the period of the last 15 years, there has been an overall growth in tyre arisings and ELT recovery [3]. Although the rise has not been constant due to the economic crisis, the trend is upwards, and it is likely to remain so as the transport and the automotive market continues to develop.

The most accurate available data on European ELT recovery is estimated by European Tyre and Rubber Manufacturer's Association (ETRMA), using national statistics reports issued by public authorities as well as annual reports released by ELT management companies. The Association represents 7800 companies in the EU and as such promotes the principle that end-of-life tyres are a valuable resource with growing potential. It advocates development, competitiveness, and growth of the tyre and rubber industry in terms of their contribution to all initiatives in favour of health, safety, and environment protection [3].

According to ETRMA's data, global recovery rates for ELT have increased significantly, but with the recovery rate of 92 %, Europe remains one of the most advanced regions in terms of treating ELT [31]. Taking into account that ELT arising in Europe amounts almost 3 million tons annualy [3], the size and the potential of those resources become obvious.

On the European ELT market, only 5 % of the total collection figure is considered as residual waste, whereas 35 % is used for energy recovery and 58 % for recycling, with approximately 2 % of ELT with the unknown end [31]. Turning tyres into secondary raw material that goes into different new products makes ELT an enabler for several other industries and an important catalyst of the circular economy.

However, although the above stated volumes and ratios have been calculated based on national authorities' data from 28 EU member countries (including the UK) plus Norway and Turkey, the official report does not contain numbers for Croatian ELT quantities. Therefore, among other goals, the research presented in this article aimed to fill that knowledge gap, too.

WASTE TYRES MARKET IN CROATIA

In Croatia, collection and recycling of ELT are done in accordance with the Law on Sustainable Waste Management [32] as well as Decree on Waste Tyres Management [33].

Pursuant to those regulations, tyre producers/importers are obliged to cover the ELT management costs by paying the prescribed fee to the public body called Environmental Protection and Energy Efficiency Fund. Since the aforesaid fee gives entirely financial character to producers' responsibility, such a management scheme is generally characterized as the tax system.

The fee is payed only for the tyres marketed in Croatia, not for those intended for export. However, since there are no domestic producers of car and other vehicles' tyres, all tyres are imported. Of course, the fee is included in the sales price of tyres and is thus prevalent to the end users.

At the end of the tyres' life span, tyre owners are compelled to separate the ELT from other waste and hand them over to a company authorized as a collector. Currently, there are 15 companies that are authorized as collectors of ELT on the entire territory of the Republic of Croatia [30].

The collectors are obliged to pass the whole collected amount of ELT to authorized processors. At the moment, there are three authorized recovery and recycling companies [34]. Out of those three, two companies are authorized as energy recovery subjects (both of them are big cement plants using so recovered energy in the course of their own production), whilst only one company is authorized for mechanical recycling, producing the secondary raw material.

The processing companies report to the Environmental Protection and Energy Efficiency Fund on a monthly basis, stating quantities of accepted and recycled waste tyres along with the amount of remaining, disposed waste. After those reports, the Fund reimburses processing companies for their ELT recycling/recovery costs, using funds coming from the importers' fee on new tyres.

Authorization of collectors and processors is declared by the Ministry of Environmental Protection and Energy and realized upon the contract with Environmental Protection and Energy Efficiency Fund. Since the Republic of Croatia is a full member of the European Union, all waste tyres management activities have to apply modern technologies and follow European environmental standards and regulations. Primarily this implies Regulation (EC) No 1221/2009 of the European Parliament and of the Council of 25 November 2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS) [35] as well as standards from the ISO 14000 Series [36] for the Environmental Management System.

The Republic of Croatia joined the European Union as the full member state in 2013, but systematic and organized waste tyres management begun in Croatia in 2007. In the period from 2007 till 2016, an average annual quantity of marketed new tyres of 21 542,32 tons has been recorded, as shown in Table 2 [37]. In the same period, the average annual quantity of collected and recycled ELT totals 19 267,07 tons.

When analyzing separate annual records, the growing trend can be noticed – only in the last year amount of marketed new tyres grew at the rate of 28 %. The quantity of collected and recycled tyres grew at a rate of 1,8 % in 2016 in comparison to 2015.

Croatia's national goal recommended by the Decree on Waste Tyres Management [33] is to recycle/recover at least 80 % of collected waste tyres annually. Figure 1 demonstrates that the last available records show the accomplishment of that goal.

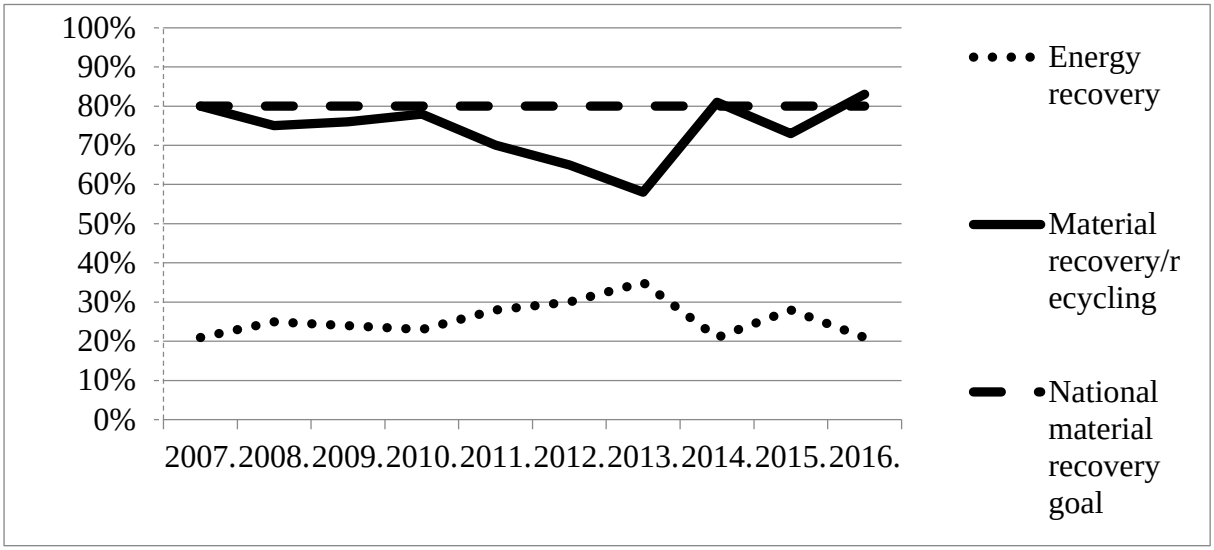

Figure 1. Accomplishment of the recommended goal for recovery/recycling of ELT in the Republic of Croatia. Source: authors' work, based on [37; p.25].

Of course, the total European quantity of retreated ELT is higher than those collected and processed in Croatia. Additionally, also, the structure of processing is somewhat different, as presented in Table 2 and Figure 2.

Evidently, material recovery in Europe has a growing trend, but on average, it reaches approximately 50 %. In Croatia, 83 % of collected tyres were recycled in terms of secondary raw material production and 17 % as energy recovery.

Another fact visible from Figure 2 is that until 2003, ELT in the European Union was allowed to landfill, which was definitely outlawed in 2006 by already mentioned Landfill Directive [10]. Therefore, the graph shows a significant fall of landfill quantities in those years, with minimum remained ratio due to non-EU-member countries.

Table 2. Quantities of marketed new tyres as well as collected and processed waste tyres. Source: Authors' work, based on [37].

Year	New tyres marketed in Republic of Croatia, t	Collected waste tyres passed for recovery/recycling, t	Mechanically recycled waste tyres resulting in secondary raw material, t	Waste tyres processed for energy recovery, t
2007	27 824,18	21 230,42	17 005,74	4 224,68
2008	27 372,47	21 224,46	16 161,08	5 063,38
2009	19 702,55	20 234,33	15 648,21	4 586,12
2010	19 913,37	19 916,65	15 610,75	4 305,87
2011	20 883,96	18 509,04	13 605,26	4 903,78
2012	16 808,05	17 031,49	12 002,58	5 028,91
2013	18 304,66	19 346,16	12 739,24	6 606,92
2014	19 468,10	17 409,56	14 097,38	3 312,18
2015	19 774,08	18 717,00	14 005,50	4 711,50
2016	25 371,78	19 051,63	15 733,40	3 318,23

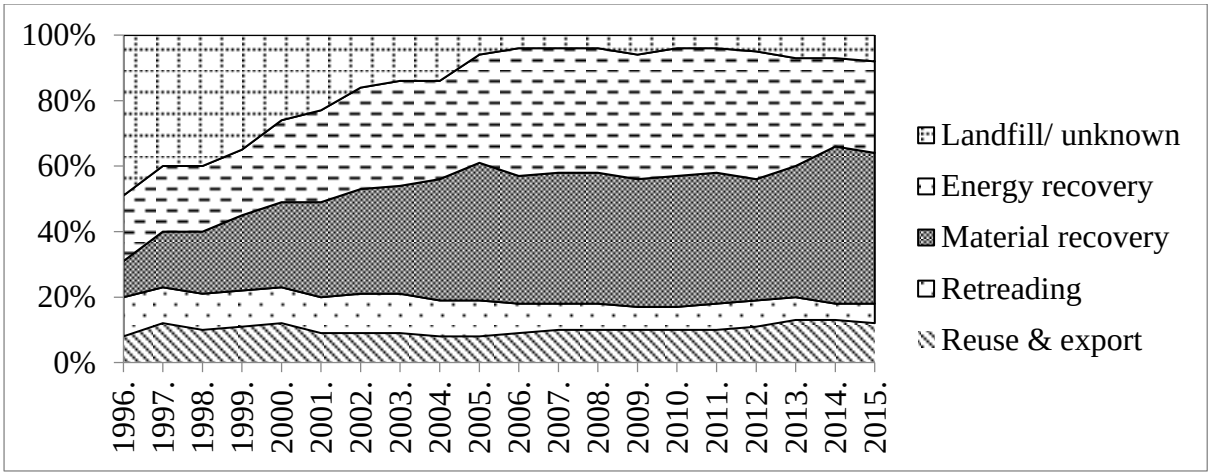

Figure 2. Treatment routes for used tyres in Europe. Source: authors' work, based on [31; p.27].

If potentials of the Croatian market for the usage of recycled tyre rubber are to be considered, appreciating the focus of this study for applications in concrete, size of the Croatian concrete market should be examined as well. Table 3 shows the trend of ready mixed concrete volumes in Croatia during the last 5 years.

Table 3. Ready mixed concrete volumes in Croatia. Source: authors' work, based on [38-42].

Year	Total produced quantity, t	Unit value, EUR/m^3
2016	3 163 510,00	25
2015	3 048 957,00	24
2014	2 758 374,00	25
2013	2 858 368,00	25
2012	3 091 517,00	27

Slow but stable growth of the concrete market is for sure one of the best possible motivation spurs for additional research and development activities regarding waste tyres applications in concrete.

DISCUSSION

Conducted situational analysis of Croatian ELT market provides detailed insight into current strengths, weaknesses, opportunities, and threats, according to the opinion of the main stakeholders. Findings are presented in Table 4.

In order to discuss the above stated strengths, weaknesses, opportunities, and threats identified by the main stakeholders of Croatian ELT market, it can be said that a significant step forward has been realized during the last decade, resulting in an organized and well - functioning market, with evolving eco-economical awareness of the entire population. However, the main threat and the obstacle for further development is the level of overall Croatian industrial production.

Croatian development chance lies not only in its geo-strategic position but also in well-educated population, availability of needed resources as well as in advanced infrastructure. But on the other side, industrial production in Croatia was based on state of the art technologies until the homeland war in the early 1990s. Unfortunately, many factories were significantly damaged during the war or extinguished during the privatization and transition process to a market economy after the war. As a direct consequence, industrial production today is underdeveloped and mostly unprepared for global competition, with few exceptions [43].

Table 4. Findings from situational analysis of Croatian ELT market. Source: authors' work.

STRENGTHS	**WEAKNESSES**
• the reduced amount of waste disposed on landfills, • cleaned all municipal waste landfills from discarded tires on the territory of the Republic of Croatia, • decreased probability of development of long-term and toxic fires at landfills, • the use of waste tires as raw material for the production of new products, • diminished utilization of natural raw materials due to the reuse of recycled materials, • establishment of the national system of continuous collection and processing of waste tires , • raising the level of ecological awareness in terms of the willingness to use products made from recycled materials, especially in construction, • by adopting new technologies, the equipment is timely acquired and modern, global trends followed.	• tyre recycling is a continuous process throughout the year, while the routine of delivery of collected ELT quantities to recycling plants shows more a seasonal character, • only one authorized mechanical recycling plant on the entire domestic market; lack of competition, • complicated and ample administration, • insufficient utilization of recycled resources in terms of final products production on a domestic market, • small domestic market due to both population size and underdeveloped industry.
OPPORTUNITIES	**THREATS**
• market attractiveness for the emergence of additional mechanical recycling subjects, • enough market capacity for the occurrence of new producers of any final products made from rubber recyclate, • finding new markets for new materials and new products, • becoming a more active participant of the EU market to which, utilizing know-how as well as import and export opportunities as a means for boosting the overall GDP growth rate, • achieving better alignment between environmental and economic initiatives.	• almost non-existing industry in Croatia for production of any final product type from rubber recyclate resources, • stock planning and logistics organization are difficult due to fluctuating availability and delivery of collected waste tyres to recycling plants, • for the same reason, ensuring stock of waste tyres that would enable continuous process is capital demanding for recycling plants, • insufficient quantities of waste tyres for a sustainable recycling industry on a domestic market, • the wrong perception that the price of rubber recyclate is higher than natural rubber resources, resulting in the opinion that there are a very few applications of final products made from recycled resources, whose properties would justify their higher price.

Structure of the ongoing industrial production in Croatia is presented in Figure 3.

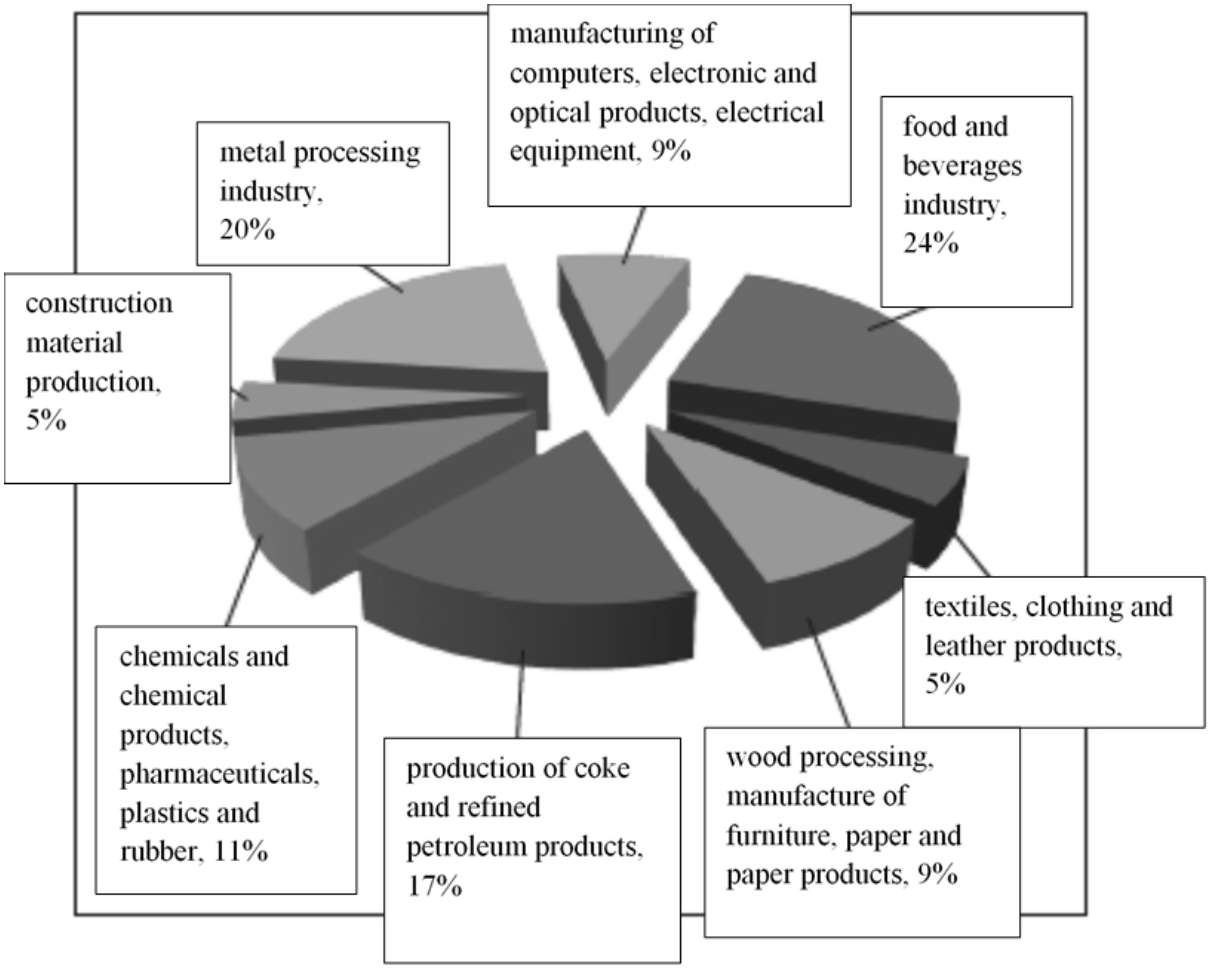

Figure 3. Structure of industrial production in the Republic of Croatia. Source: authors' work, based on [44; p.7].

The Gross Domestic Product (GDP) in Croatia was worth 54,85 billion US dollars in 2017 [45]. Industrial production had a ratio of only 2,9 % in Croatian GDP in 2017 [46], and the latest available data presented in Figure 3 show that processing of rubber, plastics, chemicals, and pharmaceuticals together amounts only 11 % of the industrial production.

Not only the size of the market determines small financial output but also the level of production, which is in Croatia, unfortunately underdeveloped. Data obtained from the only authorized mechanical recycler of the waste tyres rubber in Croatia show that generated recycled rubber resources are mostly sold in the form of basic material and only the small amount is being transformed into final products on the domestic market. More precisely, that very company has its own production of protective covers and cast rubber products made from recycled rubber. Beside them, there are only a couple of very small producers using recycled rubber resources within the country. Insight into internal records of the recycling company reveals that joined rubber recyclate demand of domestic producers generates only 17 % of their annual sales income. Remaining 83 % of income comes from the export of created resources, mainly to regular customers, big producers of different final products in Germany and England. Obviously, not only efficient collection and processing of waste tyres but increasing the level of production and creating products with higher additional value than plain resource should be seen as the tyre circular economy potential in Croatia.

Such assertions could be supported by the study conducted by Prieto-Sandoval et al. [47], who concluded that the regulation and policy determinants build the circular economy legal

framework that supports the supply side actions such as cleaner production, the development of industrial metabolisms and sustainable business models, whilst the demand side determinants, mainly represented by consumers, should be able to accept eco-innovative products in the market and acquire sustainable behavior.

As a direct consequence of such poor exploitation of produced ELT recyclate, Croatia is well below EU's average concerning the Eco lnnovation Index. It is a composite index that measures the eco-innovation performance of a country compared with the EU average and with the EU top performers [11]. In 2017 Croatia achieved a performance score that is 28 % lower than the EU average, which places it 8th from the bottom in the EU-28 eco-innovation ranking.

However, in 2015 Croatia scored 61 % of EU-average, so it rose 4 places with 18 % improvement in eco-innovation. In addition to that, Croatian scholars and professionals follow European trends by cooperating on different studies, which gives hope that circular economy potential shall be fully seized in the near future. Regarding ELT in Croatia, which is the main focus of this article, the most important studies regarding industrialization and commercialization of waste tyre rubber material and products have been ANAGENNISI – *Innovative Reuse of All Tyre Components in Concrete* [48], RUCONBAR – *Rubberised Concrete Noise Barriers* [49] and an ongoing ReCoTiP – *Development of Reinforced Concrete Elements and Systems with Waste Tyre Powder* [50].

On the European and even more global scale, Croatian share is small. But, the ecosystem is mutual, so even the smallest contribution in terms of material or energy recovery matters for the whole planet. Perhaps that environmental aspect of ELT market shall bring to overpowering the lack of domestic capital and stimulation of foreign investments, ending in the win-win situation of achieving the full potential of Croatian waste tyre rubber circular economy.

In compliance with the majority of the existing circular economy work, which is mainly done on the practical and technical levels of the actual physical flows of materials and energy in production [51], this article tried to articulate the current contribution of Croatian end-of-life tyres management activities to Croatian and European circular economy context.

CONCLUSIONS

Circular economy implies the appropriate level of society's awareness, the adoption of suitable and clear policies and tools as well as the use of modern technologies. Due to the waste tyres treatment rate above 90 %, no other waste material stream performs as high as the ELT sector in Europe [31] and fundamentally demonstrates a high circular economy potential. As such, ELT treatment can be analysed as process innovation, which is considered the most significant out of the four basic innovation types, as it can offer the most material and energy savings [13]. But, since ELT based resources and products also influence other dimensions, like the social, product and environmental innovation, at micro, mezzo and macro level, ELT recycling and reuse is even more important than that and belongs to the domain of eco-innovations. Study of the Croatian ELT market found that national legislation framework is adequate and compatible with European regulations. It ensures well and transparent functioning of the market despite complex administration that might be reduced to more acceptable proportions. Furthermore, as in the EU, material recycling and combustion of used tyres are the most technologically developed methods of handling these wastes in Croatia. The focus of this article has been primarily on material recycling since it is a source of valuable raw material that has potential in construction and other industries.

Results indicate that even though Croatian recovery structure is somewhat different from the European in favour of material rather than energy recycling, previously presented results

confirm proposition RP1, concluding that *although smaller, Croatian waste tyres market is in compliance with characteristics of the European waste tyres market in terms of legislation, collection rate and recovery structure*. Unfortunately, the study detected also the deficiencies of the ELT market in Croatia. Due to the generally underdeveloped industrial production in Croatia, waste tyre activities in Croatia can be called an approach to more appropriate waste management rather than a serious circular economy. There are still not enough industrial and commercial achievements that would make existing recycling, reuse, and recovery activities sufficiently exploited. Besides the SWOT analysis results, the market trends indcuate that the waste tyre market is still developing, indicating that RP2 cannot be accepted, thus indicating that *waste tyre market is still not a significant source of eco-innovations in Croatia since it provides opportunities for recycling, re-use, and new business models development, thus contributing to circular economy initiatives*. The transition towards a circular economy comes from the involvement of all actors of the society and their capacity to link and create suitable collaboration and exchange patterns [1]. Therefore, it seems that in the case of Croatia, only the new industrial investments would have the strength to become the real driver towards a circular economy, supplementing current advanced initiatives and activities performed by public institutions, academicians and ELT management companies.

In the end, limitations of the study need to be highlighted. This study proved that there are quantitative, qualitative, and organizational potentials in recycled rubber materials in Croatia. However, comercializig the concept needs to be additionaly anaylized since it does not happen spontaneously but is the process that needs to be supported. Therefore, suggested future research direction are particular market purposes, their reasoning by focusing on financial justification of potential usages and analysis of the possibility to trade them.

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