Closing the Loop in the Process of Manufacturing Noise Barriers and Floating Trash Barrier - Case Study

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***Abstract* – The circular economy embodies a contemporary approach centered on sustainability and waste reduction, gradually integrating into production and consumption practices. Nonetheless, it has often remained a theoretical or abstract concept across various economic sectors. This paper focuses on the potential implementation of circularity principles, using the production process of noise barriers, manufactured by the production company based in Prešov, Slovak Republic, as an illustrative example. Through a comprehensive case study, it was determined that reintegrating generated waste into the production cycle is feasible. Moreover, there is potential for a cascading effect, where original waste could be utilized across multiple production processes. This underscores how the circular economy fosters economic efficiency, innovation, and creativity in diverse areas such as design, product diversification, input sourcing, and production planning. The paper's significance lies in its thorough examination of the production process, quantifying various types of waste to uncover innovative methods of converting waste into new input materials. Additionally, it offers insights and actionable guidance towards embracing multicircularity (via a circularity spiral), along with strategies for identifying opportunities to incorporate circularity elements into production schemes. This approach promises extensive economic, environmental, and social benefits, considering product nature and usage.**

***Keywords* – Noise barrier, floating trash barrier, waste, circularity, multicircularity.**

DOI: 10.18421/TEM132-07
https://doi.org/10.18421/TEM132-07

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Received: 16 February 2024.
Revised: 19 April 2024.
Accepted: 10 May 2024.
Published: 28 May 2024.

1. Introduction

In today's industrial environment, the prevailing linear production model adopted by many companies has led to number of environmental problems, ranging from resource depletion to pollution and excessive waste generation. This linear approach, characterised by raw material extraction, production, consumption and disposal, has been the basis of industrial practices for decades [1], [2]. However, the detrimental effects of this linear model on the environment are becoming increasingly evident, requiring a transformational change in our approach to production and consumption.

Increasing concerns about environmental degradation, resource scarcity, and the urgent need for sustainable practices have prompted a shift towards a Circular Economy (CE). The circular economy is a regenerative system that seeks to redefine traditional linear models by emphasising the importance of maintaining the use of products, materials, and resources for as long as possible [3]. In contrast to the 'take, make, dispose' mentality, the circular economy promotes a closed-loop system that aims to minimise waste generation, reduce environmental impact and promote sustainable resource management.

One of the critical issues arising from linear production models is the environmental burden caused by pollution and waste.

The uncontrolled linear flow of materials through the production-consumption-disposal cycle results in serious problems such as air and water pollution, soil degradation, and the accumulation of non-biodegradable waste in landfills. To address these problems, the circular economy is proving to be a promising solution that is in line with the global commitment to sustainable development.

The European Union (EU) has been at the forefront of promoting and implementing circular economy initiatives. Recognising the urgent need to move towards more sustainable practices, the EU has put in place comprehensive policies and frameworks to integrate circular economy principles into the fabric of industries. The aim of these initiatives is to promote resource efficiency, reduce environmental impacts, and foster economic growth within the limits of our planet.

In addition, the circular economy finds synergies with the United Nations Sustainable Development Goals (SDGs) set out in the 2030 Agenda. Through the 2030 Agenda, the global community has committed itself to addressing socio-economic challenges while mitigating environmental impacts. Circular economy applications play a key role in achieving several of these goals, including responsible consumption and production (Goal 12), climate action (Goal 13), and life below water and on land (Goals 14 and 15).

The aim of this paper is to explore the aspects of circular economy application as a transformative solution to the prevailing linear production, with a focus on the possibilities of its practical implication in the production company. The article extends the current knowledge base with empirical evidence of the possibilities of applying the principles of circular economy in production process, with an emphasis on minimizing negative environmental impacts and leveraging positive impacts in terms of economics and resource management.

2. Review of Literature and Policy on the Circular Economy

The transition to a circular economy (CE) has flourished in recent years as a response to the environmental challenges posed by traditional linear production models. This literature review examines recent key academic papers that address the concept of the circular economy, its applications and its role in mitigating environmental impacts. The review also highlights EU initiatives and the global commitment to sustainability outlined in the 2030 Agenda.

Ellen MacArthur's seminal work Towards the Circular Economy provides a basic understanding of CE principles. The paper [4] highlights the need to decouple economic growth from resource depletion and waste generation by promoting a closed system.

These principles include designing out waste, keeping products and materials in use, and regenerating natural systems.

Numerous studies, such as those by [5], [6], [7], [8] point to the negative environmental consequences of linear production models. Pollution, resource depletion, and the generation of huge amounts of non-biodegradable waste contribute to climate change and biodiversity loss.

The literature offers valuable insights for both academia and industry regarding the design and implementation of circular economy practices to address environmental challenges and promote sustainable development. The paper [9] is focused on the economic implications of circular economy practices and provides empirical evidence of short-term economic gains, particularly for small and medium-sized enterprises (SMEs). The findings of this study contribute to policy makers' understanding of the real impact of circular economy initiatives, particularly on SMEs, and thus shape the decision-making of businesses and policy makers. The paper [10] examines circular economy practices in the built environment, highlighting the need for sustainable urban development. The review covers different approaches and identifies research gaps, proposing the concept of urban-rural symbiosis and a database of best practices to support cities in implementing circular economy principles. The paper [11] contributes to the literature by bridging the gap between theoretical objectives and practical strategies for implementing circular economy principles. The study conducts a review of the scientific literature on circular economy and proposes seven operational principles aligned with sustainable development: matching inputs and outputs to recovery and absorption rates, closing the system, preserving the value of resources, reducing the size of the system, designing for a circular economy, and educating for a circular economy. The paper [12] shifts the focus to the adoption of circular practices in manufacturing firms, addressing a gap in the understanding of how traditional companies are transitioning to circular models. Through a survey of 821 Italian companies, the study identifies five clusters based on their current level of circularity implementation, ranging from information-oriented companies to circular champions. Economic factors are found to be most effective in encouraging traditionally structured "linear companies" to adopt circular business models. The findings highlight the economic benefits for circular champions and suggest a differentiated approach to stimulating the circular economy, taking into account different company profiles and drivers related to regulatory pressure, resource use risks and environmental values.

The European Union has been a leader in promoting the circular economy through legislative frameworks, policies, and strategies to promote eco-design, recycling and sustainable consumption, such as the Roadmap to a Resource Efficient Europe, the EU Circular Economy Action Plan [13], [14], [15]. These initiatives have also been reflected in the policy measures of individual Member States. For example, the Slovak Republic has developed several cross-cutting strategies and regulations that aim to set a vision towards climate neutrality and sustainable development. The most important policies directly or indirectly related to the circular economy are the Sustainable Development Strategy 2030, the Environmental Strategy 2030, the Low Carbon Development Strategy and others [16], [17], [18].

Inspired by these studies and policy shifts, the paper examines the possibilities of practical application of CE principles in the company producing mobile noise barriers.

3. Material and Methods

The paper aims to determine the volume of waste generated throughout the production stages of noise barriers at production company (located in Prešov, Slovak Republic), with the goal of evaluating its potential reuse as input material for other products, aligning with the principles of the circular economy. We do not mention the name of company for reasons of commercial confidentiality. To achieve this objective, the following steps have been undertaken:

- Identifying and analyzing all stages of the production cycle, with a focus on quantifying the materials utilized and waste generated at each production site.
- Identifying and quantifying the quantities of packaging materials used for material entry into the facility.
- Summarizing the types and quantities of waste produced.
- Proposing methods for reintegrating waste into the production cycle.

During the quantification process of material usage, we relied on internal documents from the enterprise (pertaining to the year 2022), supplemented by firsthand information from production operators, production managers, and enterprise management.

4. Results

For over 20 years, the production company, based in Prešov, has specialised in the manufacture of technical textile products for a wide range of industries.

Their range includes car tarpaulins, awnings, shading solutions, party tents and shelters of various sizes and shapes. The company's product range also includes noise barriers under the Echo Barrier brand, which have been part of the company's product range for a long time.

Echo Barriers provide effective, temporary solutions for managing and mitigating noise pollution, particularly in construction environments. They not only significantly reduce the noise impact, but also address other environmental concerns associated with construction activities. These barriers are used at construction sites, demolition sites, railway and road right of ways, mining, waste management, and recycling facilities. They are also used at events such as concerts and festivals.

Their main advantages are lightweight, easy to transport, easy to use and dismantle, highly adaptable, and versatile for marketing purposes. They can also withstand harsh weather conditions.

Noise barriers are manufactured using environmentally friendly materials and processes. The Echo Noise Barrier consists of four main components:

The front outer layer: This layer of highly resilient PVC fabric protects the product from adverse weather conditions. It consists of a triple-layer 'sandwich' structure of PVC film, glass fibre fabric, and a further PVC film.

Sound absorbing composite: Located inside the noise barrier, this layer consists of a sound absorbent made from recycled materials, mainly textile waste. It prevents sound reflection by trapping some of the sound within the composite. A PVC layer is applied to one side and a waterproof and breathable membrane layer to the other, with double-sided adhesive tape to hold them in place. This predominantly cotton composite is biodegradable.

Waterproof and breathable membrane: applied to the back of the noise barrier, makes the product waterproof yet breathable. Consisting of two layers - a textile surface layer (polyester) and a PVC layer - firmly bonded together, waterproof and breathable membrane prevents water ingress while allowing the barrier to breathe freely without being hermetically sealed.

Durable reinforced mesh "Mesch": This component increases the durability of the barrier even in harsh conditions. Made from a technical PVC fabric, similar to the front layer but with a modified membrane structure, the mesh contains holes that trap sound waves and dust particles. It acts as a windbreak, significantly reducing wind speeds, especially at ground level. This layer, which is highly resistant to weather and temperature changes, is added selectively according to customer requirements.

Various input materials are used in the manufacturing process, including technical fabrics, reflective elements, trims, threads, brackets, rings, buckles, and adhesive tapes. Table 1 provides a breakdown of these input materials and their quantities used in the production of 12,866 noise barriers (representing total annual production in 2022).

Table 1. Annual material consumption in the production of noise barriers (in 2022)

ITEM	QUANTITY USED	UNIT OF MEASUREMENT
Technical PVC fabric	55701,1	m2
PVC 8509-636	12703	m2
PVC 8540-606	23963	m2
PVC 8540-543 glossy	1408	m2
PVC 8540-543 mat	1281	m2
PVC 8540-636	200	m2
PVC 8800-606	4129	m2
PVC 8800-729	1639	m2
PVC 8800-586	1345	m2
PVC 8800-543	9033	m2
Mesh	12703	m2
Waterproof and breathable membrane	61271	m2
Recycled cotton in sheets	19070	m2
Reflective strip	32646,94	m
Hemline	121947,00	m
Hemline 10/1/40	10290	m
Hemline 10/1/25	111657	m
Threads	890034	m
Thread	43919	m
Thread	143834	m
Thread	596165	m
Thread	106116	m
Brass ring (in pcs)	283658	pcs
Holders and buckles (in pcs)	19070	pcs
Double-sided adhesive tape	87559	m
A type of adhesive tape	11645	m
B type of adhesive tape	75914	m
UV printing ink (C, M, Y, K, W) in litres	360	l

On arrival at the factory, the raw materials for the noise barrier production are routed to the warehouse and logged into the internal system. Once the cutting plans and graphic designs have been finalised, the PVC technical fabric is sent to the advertising department for printing according to the specified designs.Once printed, the PVC technical fabric is sent to the cutting department, where it is cut, along with waterproof and breathable membrane and mesh, to the exact dimensions required. Production operators then apply the recycled cotton to the PVC technical fabric using double-sided adhesive tape.

The next step is to use high-frequency machines to seamlessly join the individual membrane pieces together, creating a strong and durable bond. The production process then moves to the sewing department, where trims, reflective elements, buckles, and stamps are meticulously applied.

In 2022, this operational workflow will enable the factory to produce 12,866 noise barriers.

Figure 1. Production of noise barriers at production company

Figure 2. Storage of noise barriers at production company

Our aim was to identify the types and quantities of waste that are produced in the production process in order to further reintegrate them into production. Waste in the production of noise barriers is generated not only in the production process itself, but also in the stages that precede it - i.e. in the stacking of the material, in its transport, when it is packaged and delivered on rolls and on pallets. The quantification of the waste originating from the various input materials, in the processing phase (residues, rejects), but also the waste originating from packaging materials is detailed in Table 2.

TEM Journal. Volume 13, Issue 2, pages 909-917, ISSN 2217-8309, DOI: 10.18421/TEM132-07, May 2024.

Table 2. Annual production of waste from the production of noise barriers (in 2022)

WASTE	QUANTITY USED	UNIT OF MEASUREMENT	WASTE IN KG
Technical PVC fabric			
Pallets	27,00	pcs	675,00
Rolls	393,00	pcs	1257,60
Residues 6%	3342,06	m2	3007,90
Scrap 4%	2228,04	m2	2005,20
Packaging material	639,40	m2	40,90
Mesh			
Pallets	7,00	pcs	175,00
Rolls	101,00	pcs	323,20
Residues 4%	508,12	m2	203,25
Packaging material	164,34	m2	10,52
Waterproof and breathable membrane			
Pallets	45,00	pcs	1125,00
Rolls	666,00	pcs	2131,20
Residues 6%	2450,80	m2	1225,40
Packaging material	1083,64	m2	69,40
Recycled cotton			
Pallets	294,00	pcs	7350,00
Cardboard L_profiles	1176,00	pcs	388,08
Packaging material	141,12	kg	141,12
Reflective strip			
Boxes	9,00	pcs	3,89
Rolls	329,00	pcs	32,90
Scrap (4%) and packaging material	228,53	m	2,63
Hemline			
Pallets	13,00	pcs	325,00
Packaging material	19,52	kg	19,52
Discs	1220,00	pcs	122,00
Residues 13,7%	16707,00	m	167,10
Threads			
Boxes	31,00	pcs	13,39
Rolls	913,00	pcs	91,30
Residues (2,5%) and packaging material	22250,85	m	1,47
Brass ring			
Boxes	284,00	pcs	78,95
Packaging material	7,09	kg	7,09
Scrap	1986,00	ks	19,86
Holders and buckles			
Boxes	39,00	pcs	16,85
and Packaging material	1,85	kg	1,85
Double-sided adhesive tape			
Boxes	584,00	pcs	72,42
Discs	3503,00	pcs	350,30
Packaging material			8,97
UV printing ink			
Residues	2,52	l	2,77
Packaging material	36,00	kg	36,00

In the process of annual production of noise barriers (12866 pcs), we have identified a total waste production of 21503 kg, while it is possible to divide the different types of waste into groups, which will allow their efficient entry into the next production cycle and the subsequent transformation of the linear mode of production into a circular one (with the potential of multicircularity). A special place in waste production is occupied by the wooden pallets on which the materials are delivered, which can be used without further treatment or sold off and thus re-entered into the production (or transport) cycle. Waste in the form of paper rolls, boxes, and cardboard represents 4409,78 kg of paper waste per year. We welcome the use of textile recycling, which forms the core of the noise barrier and which does not generate waste when installed, as the size of the recycled cotton board is the same as that to be used when installed in the noise barrier. However, we have observed a higher waste production in the processing of the PVC technical fabrics forming the top (front and back) layers of the noise barrier. Waste PVC technical fabrics, Mesh and waterproof and breathable membrane, account for 8530 m2 per year, representing more than 6.5% of the total input material. Taking this fact into account, it is for this type of waste that we have identified the potential for its further use in the process of producing Floating Trash Barriers.

The bore wall is designed to trap pollutants (mainly municipal solid, plastic waste) on watercourses and water reservoirs directly on the surface, in order to eliminate environmental pollution. The very determination of the use of the product and its mission is pro-environmental and is an important element in the process of environmental management, in ensuring the sustainable use and preservation (quality) of water resources. There are many variations of bore walls, which differ mainly in terms of their capabilities and methods of capturing pollutants in watercourses and water bodies.

Figure 3. Installation of floating trash barriers in the area of the Ružín water reservoir

Figure 4. Waste captured with the use of a barrier wall in the area of the Ružín water reservoir

As part of the case study, we have identified the possibility of linking the production cycle of noise barriers with the output of part of it (selected types of waste - technical PVC textiles) to the production of Floating Trash Barriers, in several dimensions (Figure 3).

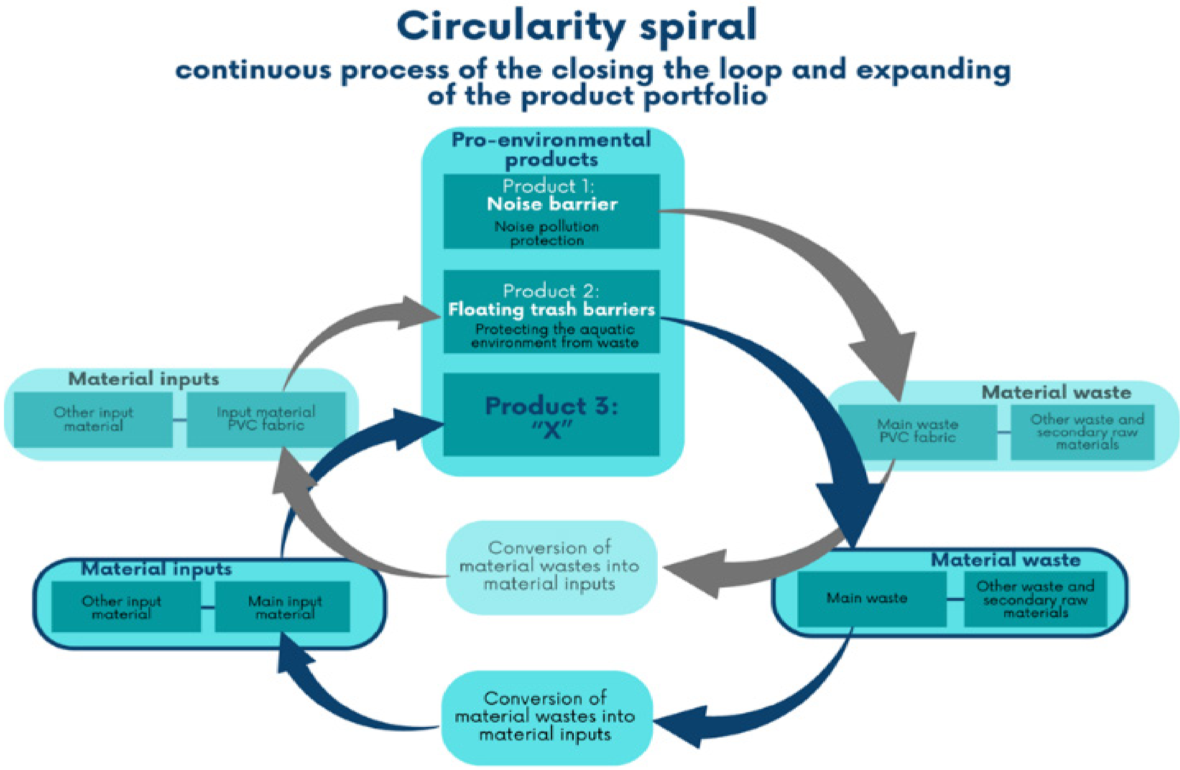

Figure 5. Spiral of circularity

• ***Product 1: Noise Barriers (commonly known as the original product) for Environmental Enhancement and Quality of Life Protection***

Noise barriers inherently serve as environmentally conscious products, designed to safeguard both the environment and the quality of life. They epitomize sustainability and circularity, as their production incorporates recycled textile waste, marking the initial step towards circularity in this manufacturing process.

• ***Utilization of Waste from Product 1 in Product 2: Repurposing Waste from Noise Barrier Production for Floating Trash Barriers***

The development of Floating Trash Barriers (Product 2) stands as another continuity of circularity within this production framework. The materials utilized originate from waste generated during noise barrier production, specifically technical PVC fabrics. The concept of manufacturing Floating Trash Barriers emerged from the necessity to effectively repurpose this waste, thereby introducing a new product into the production cycle while concurrently improving environmental quality and quality of life.

• ***Product 2: Floating Trash Barriers (Innovative Product) for Environmental Preservation and Enhanced Quality of Life***

The creation of Floating Trash Barriers, was primarily spurred by societal demands to proactively address the burgeoning issue of watercourse pollution resulting from escalating waste consumption and inadequate waste management practices. By utilizing waste materials from noise barrier production, a product primarily focused on environmental protection and quality of life enhancement, Floating Trash Barriers inherently serve as environmentally friendly products in both their function and use. This synergistic effect is further magnified by the successive closure of the production cycle into a circular framework, demonstrating the concept of multicircularity.

• ***Transformation of Waste from Product 2 (Floating Trash Barriers) into Raw Material for New Product 3 "X": Advancing Multicircularity by Repurposing Waste from Floating Trash Barriers Production for Innovative Product "X"***

The evolution towards Product 3 "X" signifies the next phase of multicircularity, characterized by the exploration of additional opportunities to utilize waste generated during Floating Trash Barriers production. This innovative approach aims to close the circle even tighter, identifying novel applications for waste materials and further enhancing environmental sustainability within the production process.

5. Conclusion

The noise barrier manufacturing process was found to have a triple positive environmental impact, marking a significant shift from a linear production cycle to a circular and potentially multi-circular production model, adding environmental value while reducing waste and conserving resources.

Despite these positive results, the research identified a number of limitations to waste reuse. Currently, the company has not been able to fully incorporate all types of waste generated into further production due to factors such as a narrower product portfolio, technical constraints of individual products, and the diverse nature of the waste, including smaller forms such as threads and adhesive tapes.

However, there is a positive trend in the reuse of PVC technical textiles due to their large volume and plastic composition. The company is continuing its efforts to find suitable methods for the reuse of other types of waste, both from the production of noise barriers and Floating Trash Barriers, as well as the development of new products (referred to in this paper as product 3 "X", as the process is ongoing). It is important to note that due to the diverse nature of the waste, several alternative methods of reintroducing it into production can be identified, potentially resulting in a range of end products under the umbrella of Product 3 "X", such as "X1", "X2", "X3", and so on.

Exploring elements of sustainability and circularity throughout the production cycle remains a focus of our ongoing investigation as we strive to maximise environmental benefits and optimise resource use.

Acknowledgements

This article is one of the outputs of the research project BIN 02_2021_024 "Applied research for the improvement of acoustic properties of mobile noise barriers and ecological use of waste generated during their production" benefits from a 1.197.226,- € grant from Iceland, Liechtenstein, and Norway through the EEA Grants. The project has been co-financed from the State Budget of the Slovak Republic in the amount of 15%.

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