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Circular Economy and Its Place in a Modern Manufacturing Enterprise

Lucia Knapčíková[1*], Rebeka Tauberová[2], Ivana Klačková[3], Annamária Behúnová[4]

[1]Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Bayerova 1, 08001 Prešov, Slovakia
[2]Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Bayerova 1, 08001 Prešov, Slovakia
[3]University of Žilina, Faculty of Mechanical Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia
[4]Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Letná 1/9, 042 00, Košice, Slovakia

Abstract

The circular economy is a key tool for addressing problems associated with excessive consumption of natural resources and environmental pollution. In the context of a manufacturing enterprise, implementing circularity principles represents not only ecological responsibility but also an opportunity to enhance the enterprise's efficiency and competitiveness. Research article aims to examine how a specific enterprise uses these principles in practice and what impact they have on its production processes and costs. It presents an opportunity to explore how an enterprise reduces waste, recycles materials, and optimises production, thereby contributing to environmental protection and enhancing its competitiveness. In addition, the circular economy enables enterprises to plan more effectively and manage their resources, thereby reducing the need for new raw materials and energy inputs, which has a direct impact on costs and profitability. The implementation of these principles can also positively impact the enterprise's image on the market, as an increasing number of consumers and partners prefer companies that prioritise sustainability and responsible environmental behaviour.

Keywords: Circular economy, Manufacturing Enterprise, Waste, Efficiency

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*Corresponding author. Email: lucia.knapcikova@tuke.sk

1. Introduction

Contemporary society and the economy are facing challenges associated with the unsustainable use of natural resources, population growth, environmental pollution, and climate change [1]. In the context of these challenges, the concept of circular economy is increasingly being applied, offering an alternative to the traditional linear model of "take–produce–consume–throw away" [2]. The response to these problems is the emergence of a circular economy, which redefines traditional production and consumption patterns [1]. The primary goal of the circular economy is to create closed material flows, in which waste is viewed as a valuable resource [3]. The circular economy supports the efficient use of resources, recycling, reuse and extension of the life cycle of products, thereby minimising waste generation and negative impacts on the environment. In the modern manufacturing enterprise environment, the circular economy is becoming a key element not only for environmental sustainability but also for increasing efficiency and competitiveness [4]. According to the state of the art of the presented research, it was focused on the monitoring of scientific articles with relation to the implementation of the circular economy, which can bring not only environmental but also economic benefits, such as cost reductions, new business models and improved brand

reputation. This article analyses the concept of the circular economy, its implementation in manufacturing enterprises, and identifies the main challenges and opportunities associated with the transition to a circular economy model. Industrial development in the 20th century was closely linked to the linear economy model, characterised by the unlimited extraction of primary resources and the production of waste [4]. However, growing environmental problems, resource scarcity, and climate change require a fundamental transformation of production processes. The circular economy provides a systematic approach to sustainable development, grounded in the principles of renewal, recycling, and product life extension [5]. It is becoming part of public policies, business strategies, and research initiatives. Combined with digitalisation (the so-called "digital circular economy"), it has the potential to transform the way we produce and consume completely. The circular economy represents a fundamental shift in the way we understand the economy. It is more than just an environmental strategy – it is a comprehensive systemic approach that combines ecological, economic, and social aspects of development. Although its implementation presents several challenges, the potential benefits for society and the planet are enormous [6].

2. State of the Art

As part of the manufacturing process, various knives are processed and then sorted as iron waste after use. The waste is collected in containers located outside the enterprise where multiple cuttings are found. The recycling process of waste materials from the manufacturing enterprise is presented by Fig. 1. Since it is pure iron, the enterprise also collects so-called sheets, wires and tubes, which are also sorted and sold by weight. Overall, the waste is divided into three main categories: pure iron, contaminated iron and hazardous liquids.

Figure 1 Recycling Process of the Waste

Resin iron is a raw material that can be reused or sold. Contaminated iron requires additional processing or special disposal. Additionally, the enterprise processes various types of iron scraps that arise during the manufacturing process. These scraps are also collected and sold by weight. The enterprise must ensure proper waste recording and sorting, with all processes subject to strict standards. Hazardous liquids generated during various production processes are collected in special containers and recorded as hazardous waste. Fig. 2 illustrates the floor plan of the production enterprise where the implementation of the circular economy was carried out. The manufacturing hall houses production, two paint shops for painting and surface treatment of products, welding workplaces, machine tools, and assembly and completion of steel parts (units) for forklift pallets, low-lift, and high-lift trucks.

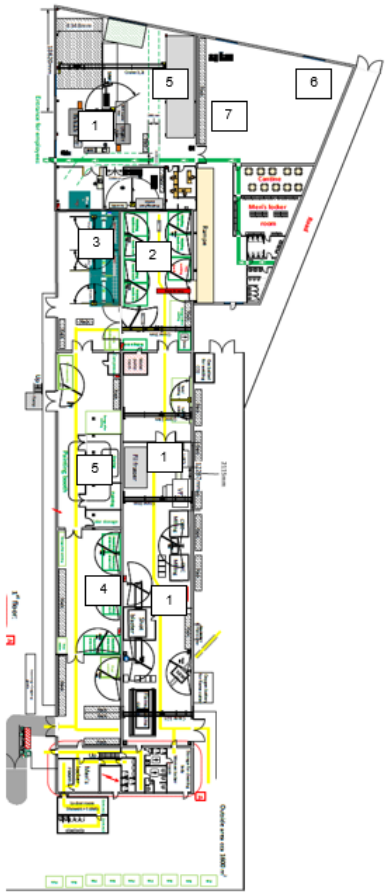

Figure 2 Layout of the Manufacturing Enterprise

A warehouse is used to store materials and final products. The operation encompasses the storage of input semi-finished products and subcontracts, the preparation and cutting of semi-finished products, the machining of parts, the welding of parts, surface treatments, the assembly and completion of products, inspection, storage, and dispatch of finished products [7]. The floors of the entire production facility, as well as the warehouse, including areas for storing and handling pollutants, are equipped with a poured industrial floor made of concrete, treated with Sikafloor 2 SynTop, a cement screed for concrete floors with high operational loads [8].

- When operating, hazardous waste "H" and waste of category "O" are generated directly in individual objects. These are temporarily collected separately in designated areas at the locations where they are generated.
- The collected waste is marked with hazardous waste identification sheets (hereinafter referred to as ILNO) and signs for waste of category "O" - other.

As part of the analysis of the current state of the enterprise, it was found:

1. Waste collection and storage areas are designed, constructed and operated in such a way that there is no undesirable impact on the environment and no damage to tangible assets [6],[8]. Waste collection and storage areas can be located in various settings, including open areas, shelters, buildings, and underground and above-ground tanks. Waste collection and storage areas are collectively referred to as waste storage facilities.
2. The area designated for hazardous waste collection and storage must be protected against harmful substances, reinforced and impermeable, and hazardous waste must be protected from external influences
3. During hazardous waste collection and storage, effective capture of polluting liquid substances must be ensured.
4. Warehouses for products and preparations with the same hazardous properties as the stored hazardous waste may also be used for the collection and storage of hazardous waste, while hazardous waste must be stored in such a way as to prevent confusion [7],[9].

Storage areas for the collection and storage of hazardous waste must meet the same technical and safety requirements as storage areas for the storage of chemical substances, preparations, and products with the same hazardous properties as the hazardous waste collected and stored [10].

Containers, barrels and other packaging in which hazardous waste is collected and stored must [11]

- be distinguished from equipment not used and not intended for waste management, for example, by distinguishing it by shape, description or colour.
- ensure protection of waste from such external influences that could cause undesirable reactions in the waste, for example, by the occurrence of a fire or explosion.
- be resistant to mechanical damage,
- be resistant to chemical influences

For example, in the paint shop, rinsing liquids are collected that circulate during the treatment process, but degrade and become polluted over time, and are therefore discharged into special containers. [12] The enterprise then registers them as hazardous waste, and serious tickets are issued for this waste to ensure its proper disposal. The enterprise has an accurate list of chemical substances and types of waste that are collected there. This list serves to record and control all hazardous substances accurately. The enterprise maintains a so-called waste bill of materials, which details the individual types of waste and the method of their disposal.

3. Work Methodology

To increase the efficiency of materials and waste management at a manufacturing enterprise, it is necessary to consider expanding existing processes and introducing modern solutions that will contribute to optimising production, minimising environmental impact, and maximising the use of raw materials [13]. The main part of the production program is steel nodes and components for forklifts of various shapes and sizes. The average weight of these components is approximately 300 kg. The estimated production volume is around 70 pieces per week, which means approximately 3200-3400 pieces per year. However, the actual volume and assortment of production are adjusted to current market requirements. During operation, hazardous waste "H" and waste of category "O" are generated directly in individual facilities. These are temporarily collected separately in designated areas at the places of their generation.

Regarding this input information, it is necessary to improve:

- Process automation and digitalisation

For even better organisation of waste management, it would be beneficial to implement a digital material and waste tracking system [14]. By utilising advanced sensors, RFID technology, and intelligent software, the enterprise would gain an accurate understanding of the movement of raw materials and the potential for their further use. Such a system could automatically record waste generation, monitor inventory and prevent excessive accumulation of materials.

- Optimisation of ferrous waste processing

More efficient management of metal scrap would enable even better sorting and processing. For example, the use of special magnetic separators would simplify the separation of clean and contaminated iron directly in the production hall. It would reduce the need for additional manual handling and increase the accuracy of sorting [12], 14]. Additionally, it would be possible to utilise technologies for crushing and solidifying metal chips, which would simplify their storage and transportation [15].

- More efficient management of chemicals

In the area of handling hazardous liquids, it is important to implement solutions that allow their safe storage and

recycling [7], [9]. By introducing special filtration systems, it would be possible to extend the life of cooling emulsions and reduce the need for their replacement. Additionally, considering the use of systems for regenerating rinsing liquids in the paint shop would be beneficial, as it would contribute to reducing the volume of chemical waste and the associated disposal costs [16].

- Improving logistics and storage of materials

Efficient storage space organisation is key to process optimisation. Utilising vertical storage systems or mobile racks can increase warehouse capacity and conserve space in the operation [12],[17]. In addition, dynamic inventory recording could be introduced, which would automatically alert to shortages or surpluses of materials, thus preventing waste.

- Introducing training and increasing environmental awareness among employees

The effective functioning of the circular economy also depends on the attitude of employees [2], [18]. Regular training on proper waste sorting, optimising material consumption and environmentally responsible behavior could significantly contribute to process improvement. Internal competitions and rewards for ecological ideas that help the enterprise save resources can also be motivational.

- Clear reporting and collaboration with experts

Streamlining records and regularly evaluating processes are essential for long-term improvement. The enterprise could introduce detailed reporting not only for internal needs, but also in cooperation with external organisations dedicated to ecological production and waste treatment [3]. Creating strategic partnerships with recycling enterprises and research institutions could bring innovations and support sustainable materials management [9].

All of the above measures would contribute to more efficient materials management, reduced environmental impact and better waste management [12]. The integration of modern technologies, optimisation of production processes, and an emphasis on environmental responsibility would enable the enterprise not only to meet legislative requirements but also to become a model in the field of sustainable industry [19].

4. Circular Economy in the Manufacturing Enterprise

The circular economy is a modern approach to resource management that minimises waste and maximises efficiency. To achieve these goals, it relies on several basic pillars [15],[18]:

1. Product and process design:

Every product should be designed with an emphasis on longevity, ease of repair and recyclability. It means using modular solutions, durable materials and environmentally friendly production processes that minimise waste from the initial development phase. Smart design also enables the remanufacturing and reuse of components, significantly extending the life cycle of products [19].

2. Resource efficiency:

One of the key goals is to optimise the consumption of raw materials and energy, thereby preventing waste. In practice, this means using by-products of production, recycling materials and implementing energy-saving technologies. The industry should utilise local and renewable resources, thereby reducing the environmental impact caused by the transportation of raw materials.

3. Circulation of materials and products:

The circular economy seeks to keep materials and products in circulation for as long as possible. Recycling, remanufacturing and reusing products contribute to this. Take-back systems play a crucial role in this process, enabling the efficient processing of used products and their transformation into new ones without compromising the quality of raw materials [20].

4. Renewable energy sources:

The transition to renewable energy sources is crucial for reducing emissions and protecting the environment. Solar, wind, hydro and geothermal energy are gradually replacing fossil fuels, and modern technologies for the accumulation and efficient distribution of energy support their use. Additionally, intelligent energy solutions, such as recuperation systems and smart grids, enable the maximum utilisation of available energy with minimal losses [13],[20].

5. Changing consumer behaviour:

Consumers play a crucial role in transitioning to a sustainable consumption model. Instead of one-time purchases, models of sharing, renting and repairing products are preferred. Platforms for exchanging and selling used items are also becoming popular, thereby extending the life of products and reducing waste. Education, legislative measures and the growing social responsibility of companies support this change in behaviour [5],[16],[19].

6. Innovation and digitalisation:

Modern technologies offer new opportunities for the efficient management of material flows and production processes. The Internet of Things (IoT), artificial intelligence, and blockchain enable real-time monitoring of the product life cycle, optimising production and minimising losses [20]. Additionally, digital platforms facilitate the exchange and reuse of resources, thereby creating a connected and efficient circular economy, as represented in Fig. 3, where the main pillars of the circular economy are presented. Manufacturing enterprise has an efficient material and waste management system, applying the principles of a circular economy. Since the company mainly works with iron, it has dedicated storage areas measuring 2 × 3 meters, where the materials are sorted and further processed. The iron material passes through a conveyor that divides it in half. The first and most important type of material is the iron itself, followed by consumables and by-products, which are used for further processing.

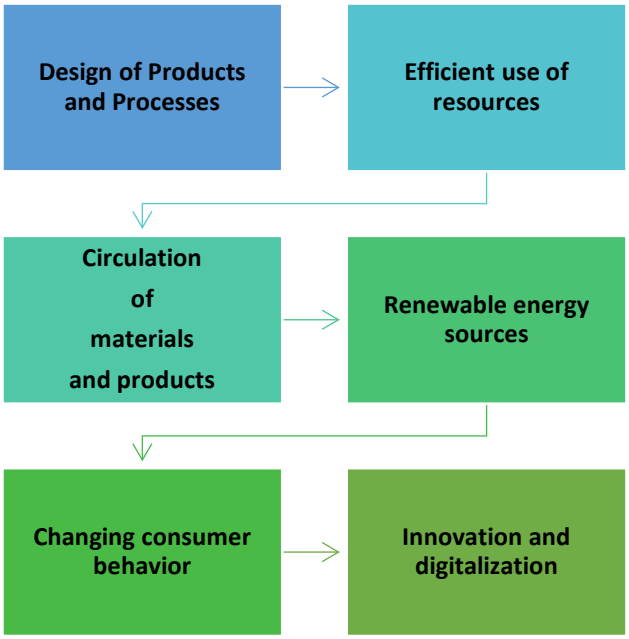

Figure 3 Main Pillars of Circular Economy

The use of recycled materials not only reduces production costs but also helps maintain environmental balance by reducing waste and rationalising the use of natural resources [20]. In this work, a proposal for introducing a system to return and sort metal scrap and worn-out products was selected from the proposed options. This solution is not only practically feasible within the existing conditions of the enterprise, but also represents an economically efficient approach to material processing.
The manufacturing enterprise uses internal processes to collect residues and reintegrate them into production, such as the recovery of materials (e.g., metal waste), cooperation with customers for the collection of used products, and energy recovery of residues. The enterprise sees new modern approaches in digital technologies as support for the circular economy itself. Also, the use of digitalisation for monitoring the life cycle of products, monitoring material flows and streamlining logistics. Furthermore, it is the implementation of technologies such as:

- IoT sensors for monitoring usage,
- blockchain for tracking the origin of materials,
- digital twins of products.

Conclusion

With increasing pressure to protect the environment, the limited availability of natural resources and changing consumer behaviour, more and more companies are turning to more sustainable business models. One of the most promising approaches is the circular economy, which emphasises the efficient use of resources, extending the life cycle of products and minimising waste. For manufacturing companies, transitioning to a circular model represents a significant opportunity to enhance competitiveness and drive innovation. The circular economy represents a transformative approach to sustainable production, which is essential in the context of the climate crisis and the growing material burden. Modern manufacturing companies that implement the principles of the circular economy gain not only environmental but also economic benefits. However, the introduction of circular processes requires a systemic approach, investment, cooperation and a long-term vision. The implementation of the circular economy in a manufacturing enterprise brings not only environmental benefits but also significant economic and strategic advantages. Within the framework of the presented manufacturing enterprise, which gradually adapts to circular principles, it becomes more resilient, efficient, and innovative in a constantly changing market environment. Using circular economy innovations within a manufacturing enterprise is not only an environmental imperative but also an economic opportunity. A proprietary approach based on redesign, take-back and digitalisation allows companies to not only minimise waste, but also create new values and business models. Compared to other methods (such as product as a service or industrial recycling), the hybrid model represents a flexible path to sustainability and innovation.

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