BioFlux ProEnvironment Original article
ProEnvironment 17/59 (2024) 220 - 225

Risk Assessment in the Industry of Plastic Waste Recycling. Note II: Technological and Economic Risks

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Received 2 October 2024; received and revised form 17 October 2024; accepted 4 December 2024; Available online 30 December 2024

Abstract

Risk assessment and management in the plastic waste recycling industry are essential to ensure sustainability and operational efficiency. Proactive and integrated approaches, which include health and safety measures, environmental protection, operational improvement, economic management, regulatory compliance and social responsibility, can help reduce negative impacts and maximize long-term benefits. The aim of the study is to develop risk matrices for health and safety risks for workers in the plastic waste recycling industry, and environmental risks for the plastic waste recycling industry. The plastic waste recycling industry faces significant economic risks that affect the viability and profitability of companies. This study shows that there are multiple technological risks that affect the efficiency and viability of operations in the plastic waste recycling industry. The quality of recycled products may be inferior to new ones due to variability and contamination of materials, as well as their degradation through repeated reprocessing.

Keywords: eqipment, fluctuations, impact, probability, raw materials.

1. Introduction

In the recycling process, collected plastic can vary in quality and composition, affecting recycling processes. The variable quality and composition of collected plastic is a major challenge in recycling processes.

These variations can affect the efficiency, costs and quality of the final recycled product. The main management measure imposed on the operational risk category is the development of a rigorous waste sorting and classification system [5, 9].

Equipment failures or inadequate performance can disrupt processes. Equipment failures or inadequate performance in the plastics recycling industry can have a significant impact on the efficiency, costs and quality of recycling processes. Identifying and managing these problems is essential to ensure the efficient operation of recycling facilities [2]. Common equipment-related problems are wear and tear and damage to the equipment due to mechanical components such as cutting blades, conveyor rollers and motors, which can wear and deteriorate over time. Problems such as bearing failures, broken conveyor belts and misalignment of components can lead to mechanical failures resulting in complete equipment shutdown, increased downtime and reduced production capacity. Failures in control systems, sensors, wiring and electronic components can affect equipment operation. Equipment that is not operating at optimal capacity may have inadequate performance in sorting, grinding and processing plastics [1, 6].

Economic risks may arise due to fluctuations in raw material prices. Prices of recycled materials may vary depending on market supply and demand.

Also, high operating costs such as those associated with waste collection, transport and processing can be significant. Management measures imposed are the optimization of logistics and the adoption of cost-effective technologies [2, 7].

The waste recycling industry faces significant legislative and regulatory risks that can impact the operations, costs and long-term viability of companies in this sector. Legislative and regulatory risks can arise due to environmental legislation that can be frequently amended to respond to new challenges and sustainability objectives, which can impose new requirements on the recycling industry. The consequence of this is that companies must quickly comply with new regulations, which can involve additional costs for adapting processes and purchasing new equipment. Legislation can impose strict quality standards for recycled materials, to ensure that recycled products are safe and effective for users, with negative consequences in the sense that, increasing processing costs to comply with these standards, which can affect profitability. Regulations may impose strict limits on greenhouse gas emissions and other pollutants, as well as the responsible management of waste resulting from recycling processes, which leads to the need to invest in emission reduction and waste management technologies, resulting in an increase in operational costs. Restrictions on the import and export of waste and recycled materials can affect trade flows and the supply of raw materials. Difficulties may arise in the supply of materials and the sale of recycled products on international markets. Management measures imposed for this category of risks consist of continuous monitoring of regulations and rapid adaptation to new requirements [1, 9].

The analysis and management of these risks are essential actions for the success and sustainability of the plastic waste recycling industry. Proactive and integrated approaches can help reduce negative impacts and maximize long-term benefits.

The aim of the study is to develop risk matrices for technological and economic risks for the plastic waste recycling industry.

2. Material and Method

A risk matrix is a tool used to assess and prioritize risks based on their likelihood of occurrence and impact. A risk assessment matrix, also known as a risk control matrix, is a tool used during planning to assess the risks of a project. It helps identify and capture the likelihood of risks occurring, as well as assess the potential damage or disruption they could cause [8]. Taking into acccount the aim of the study, we mwntion that the risk matrix was developed to assess and prioritize technological and economic risks based on their probability of occurrence and impact [3, 4]. A risk assessment matrix, also known as a risk control matrix, is a tool used during planning to assess the risks of a project. It helps identify and capture the probability of risks occurring, as well as assess the potential damage or disruption they could cause.

3. Results and Discusions

Economic risks for the plastic waste recycling industry. Economic risks in the plastic waste recycling industry cover a wide range, from issues related to the fluctuation of raw material prices, which refer to the value of recycled plastic materials, which can vary significantly depending on market supply and demand, affecting the profitability of companies, to operational costs, which refer to investments in advanced technology and compliance with environmental regulations, which can significantly increase operating costs, to which are added political instability and environmental regulations, competition and barriers to entry in the relevant market, dependence on waste streams and/or innovative aspects and technological innovations.

The plastic waste recycling industry is subject to significant economic risks that may affect the viability and profitability of the companies involved. Thus, the fluctuation of recycled raw material prices concerns issues related to market volatility and especially competition with the emergence of new raw materials and materials. Operational costs mainly refer to investments in technologies and compliance costs. Political instability and environmental regulations refer to changes in government policies and subsidies and incentives, and competition and barriers to entry refer to competitive markets and various obstacles.

Dependence on waste streams refers to risks related to the variability of waste quantities and their contamination. Risks related to innovation and technological adaptability refer to the need for constant innovation and adaptation to new materials.

The prices of recycled plastics can fluctuate significantly depending on market demand and supply. A sudden drop in prices can reduce profit

margins and make recycling unprofitable. During periods of low oil prices, the production cost of new plastics can be lower than that of recycled materials, making them more attractive to producers.

Implementing new recycling technologies and upgrading existing equipment requires significant investments. High initial costs and long payback periods can be risky for small and medium-sized enterprises. Compliance with strict environmental and safety regulations can generate additional costs for businesses. These include costs of obtaining certifications, monitoring emissions, and managing hazardous waste. Changes in recycling and waste management legislation can directly affect the industry. For example, bans on the export of plastic waste to certain countries or the introduction of taxes on unrecycled plastics can negatively impact the business of recycling companies. In some regions, government subsidies and incentives for recycling can fluctuate, affecting the financial stability of companies that rely on these funds. The increase in the number of companies in the recycling sector can lead to intense competition, which can reduce prices and profit margins. The recycling industry requires large initial investments in equipment and infrastructure. In addition, obtaining the necessary certifications and complying with environmental regulations can represent significant barriers to new market entrants. The quantity and quality of plastic waste collected for recycling can vary significantly. A decrease in the volume of waste collected can negatively affect production and revenue. Plastic waste that is contaminated with other materials may require additional cleaning and sorting processes, thus increasing operational costs and reducing recycling efficiency. Recycling technologies are evolving rapidly and companies need to continuously invest in research and development to remain competitive. This can involve significant costs and risks related to the adoption of new technologies. The emergence of new types of plastics or composites may require the adaptation or replacement of existing recycling equipment, implying additional costs. The risk matrix and the risk level value matrix are presented in Table 1 and Table 2.

Table 1. Economic risk matrix for workers in the plastic waste recycling industry

Probability/Impact	Impact redus	Impact moderat	Impact mare
Reduced probability	-	-	-
Moderate probability	-	-	High operational costs, Political instability and regulations, Technological innovation and adaptability
High probability	-	Competition and entry barriers	Fluctuation in raw material prices, Dependence on waste streams

Table 2. Probability, impact and risk level values for the risk matrix belonging to the economic domain for workers in the plastic waste recycling industry

Risk	Probability	Impact	Level
Fluctuation in raw material prices	4	4	16
High operating costs	3	4	12
Political instability and regulations	3	5	15
Competition and entry barriers	4	3	12
Dependence on waste streams	4	4	16
Technological innovation and adaptability	3	4	12

According to the risk matrices and risk level values, the following results emerge:

- fluctuations in raw material prices, political instability and environmental regulations, and dependence on waste streams pose a high risk, requiring immediate attention and urgent measures;
- high operational costs, competition and entry barriers, innovation and technologic

aladaptability pose a moderate risk, requiring control and monitoring measures.
- in this case, no low risks were identified.

By analyzing the risk matrices and risk level values, in order to properly manage economic risk in the plastic waste recycling industry, the following control measures are recommended, depending on the risk category:

- economic risk management measures;
  - ✓ diversification of income sources;
  - ✓ development of additional services, such as waste management consultancy or the sale of value-added recycled products;
  - ✓ partnerships with other industries to create stable flows of recyclable waste;
- efficiency of operational costs;
  - ✓ implementation of energy and resource efficient technologies and processes;
  - ✓ optimization of the supply chain and reduction of losses in the recycling process;
- monitoring and adaptation to government policies:
  - ✓ actively following changes in legislation and quickly adapting to new regulations to avoid penalties and benefit from new opportunities;
  - ✓ involvement in dialogue with authorities to influence policies and regulations favorable to the industry;
- investment in research and development;
  - ✓ investing in innovation to develop more efficient recycling processes and high-quality recycled products;
  - ✓ collaborating with research institutions and other companies to share the risks and costs of technological development;
- effectively managing human resources;
  - ✓ continuously training employees to improve productivity and reduce operational risks;
  - ✓ creating an attractive work environment to retain and attract talent in the recycling industry.

Technological risks for the plastic waste recycling industry. The plastic waste recycling industry faces various technological risks that can affect the efficiency and viability of operations. These mainly relate to the quality of recycled products and technological innovations, since recycled plastics may have inferior properties compared to new ones, affecting their applicability and acceptance in the market, to which is added the need to keep up with technological innovations and implement new efficient processes can be a continuous challenge. In addition to these risks, there are also those related to operational and maintenance issues, process integration and automation, and residual and secondary waste management.

The quality of recycled products refers to the variability of materials, material contamination and material degradation. Plastic waste comes from diverse sources and has different chemical compositions. This variability can affect the consistency and quality of recycled materials. Plastic waste can be contaminated with other materials (such as metals, glass, organic residues) that complicate the recycling process and affect the quality of the final product. Repeated reprocessing of plastic can lead to degradation of its physical and chemical properties, thus limiting the use of recycled material in high-performance applications.

Technological innovations and adaptability refer to the rapid evolution of technologies and the high costs of implementation. The recycling industry is in a state of constant change, with new technologies and recycling processes emerging frequently. Businesses must constantly invest in upgrading equipment and adopting new technologies to remain competitive.

Adopting new technologies can require significant investments in equipment and employee training, which can be prohibitive for small and medium-sized businesses.

Operational and maintenance issues include the efficiency and maintenance of equipment. Recycling equipment must operate at optimal parameters to ensure process efficiency. Any equipment failure or inefficiency can lead to production losses and increased operating costs. Regular maintenance and failure prevention are essential to avoid unplanned production downtime. The cost and complexity of maintenance can be a significant challenge.

Process integration and automation refers to the complexity of integration, coupled with the dependency on software and control systems. Integrating the different stages of the recycling process into an efficient and automated workflow can be difficult. Compatibility issues between equipment from different manufacturers can further complicate this issue. Automating recycling processes requires advanced control systems and powerful software packages. Technical problems or software failures can seriously disrupt profitable operations.

Residual and secondary waste management includes the management of non-recyclable waste, and in this case, its impact on the

environment must be monitored. The recycling process often generates secondary waste that must be managed appropriately.

Identifying and implementing effective methods for treating or disposing of this waste can be challenging. Inadequate management of residual waste can lead to environmental problems, including soil and water pollution, which may incur additional penalties and costs for businesses.

The risk matrix and the risk level value matrix are presented in Table 3 and Table 4.

According to the risk matrices and risk level values, the following results are obtained:

- the quality of recycled products and operational and maintenance problems present a high risk, requiring immediate attention and urgent measures.
- equipment failure, technological innovation and adaptability, process integration and automation, residual and secondary waste management present a moderate risk, requiring control and monitoring measures.
- in this case, low risks are not recorded.

Table 3. Technological risk matrix for workers in the plastic waste recycling industry

Probability/Impact	Reduced impact	Moderate impact	High impact
Reduced probability	-	-	Biological contamination
Moderate probability	-	-	Mechanical accidents, Burns and thermal injuries
High probability	-	Manual handling of heavy loads, Unfavorable working positions, Stress and mental health	Exposure to toxic chemicals

Table 4. Probability, impact and risk level values for the risk matrix belonging to the technological domain for workers in the plastic waste recycling industry

Risk	Probability	Impact	Level
Quality of recycled producte	4	4	16
Equipment failure	3	5	15
Technological innovation and adaptability	3	4	12
Operational and maintenance issues	4	4	16
Process integration and automation	3	4	12
Residual and secondary waste management	4	3	12

By analyzing the risk matrices and risk level values, in order to properly manage technological risk in the plastic waste recycling industry, the following control measures are recommended, depending on the risk category:

- quality of recycled products;
  - ✓ establishing strict standards for sorting and preparing input materials;
  - ✓ implementing rigorous quality control protocols to ensure the consistency of recycled products;
- equipment failure;
  - ✓ regular maintenance and inspection of equipment to reduce the risk of breakdowns;
  - ✓ implementing a robust preventive maintenance program to minimize downtime;
- technological innovation and adaptability;
  - ✓ investing in research and development to stay abreast of new technologies;
  - ✓ continuous training of employees to adapt to new technologies and processes;
  - ✓ adopting advanced sorting and recycling technologies that can more effectively handle various types of plastics and contaminants;
- operational and maintenance issues;
  - ✓ optimizing equipment configuration to maximize operational efficiency;
  - ✓ continuous monitoring of equipment performance and adjusting processes as needed;
- process integration and automation;
  - ✓ investment in automation and control systems that efficiently integrate all stages of the recycling process;

- ✓ ensuring compatibility between different equipment and software systems to avoid integration problems;
- residual and secondary waste management;
  - ✓ developing effective strategies for secondary waste management;
  - ✓ implementing advanced technologies for treating or recovering residual waste.

4. Conclusions

The plastic waste recycling industry faces significant economic risks that affect the viability and profitability of companies. Fluctuations in recycled raw material prices and competition with new materials can reduce profit margins. Increased operational costs due to investments in advanced technologies and compliance with environmental regulations, political instability and legislative changes affect financial stability. Dependence on waste streams, variability in their quantities and quality, as well as the need for constant innovation and adaptation to new materials impose additional pressures on companies. Also, intense competition and high entry barriers, such as high initial costs and certification requirements, further complicate the economic landscape of the industry.

This study shows that there are multiple technological risks that affect the efficiency and viability of operations in the plastic waste recycling industry. The quality of recycled products may be inferior to new ones due to variability and contamination of materials, as well as their degradation through repeated reprocessing. Maintaining competitiveness requires continuous investment in new technologies and equipment, which can be costly, especially for small and medium-sized enterprises. Operational and maintenance issues, as well as process integration and automation, add complexity and can lead to production disruptions and increased costs. Effective management of residual and secondary waste is essential to avoid negative environmental impacts and possible penalties.

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