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Life Cycle Assessment of Marine Waste Recycling Practices: Comparative Environmental Impacts and Determinant Factors

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ABSTRACT:

In recent years, institutions and civil society have increased their awareness and commitment to protecting the marine ecosystem. This change has led to the creation of a specific Sustainable Development Goal (SDG) for the protection of the marine ecosystem, as part of the United Nations Sustainable Development Goals.
Despite these efforts, the situation remains unchanged. Numerous companies are taking steps to contribute to solving the problem, turning it into an opportunity.
This paper addresses the issue of marine litter, with a focus on management during the recycling phase. In particular, it analyses how materials found near the sea are recycled, assessing which of these techniques are most effective from an economic and environmental point of view.
The theoretical topics covered in Chapter 2, the “literature review”, were used to identify an answer to the research question. Among the methods used is the LCA methodology, which allows all the impacts of a process to be identified and tracked throughout its useful life. This model is essential for tracking the life of a product or process, from its creation to its reuse. It is fundamental to ensuring a complete and accurate analysis.
Furthermore, the circular economy is another topic of fundamental importance for this sector, to which a large part of the literature is currently dedicated.
Many companies in this sector start with this type of business idea and then develop more innovative and sustainable ideas.
As discussed in Chapter 3, the method used for this research is a semi-structured interview conducted with five participants representing three companies. Seaqual is a Spanish company that specialises in the production of recycled yarns. Acquafil is an Italian company operating in the yarn recycling sector, with a presence complementary to that of Seaqual. Erion Packaging is another Italian company involved in packaging recycling.
The first two companies operate in the waste collection and recycling sector, with the aim of obtaining a final product from these materials. Erion Packaging has proved to be a useful tool for comparing other recycling methods.
In the concluding chapter, in addition to demonstrating the existence of a method that stands out for its environmental and economic sustainability compared to others, the difficulties encountered during the implementation of this project will be examined and suggestions will be provided for future researchers who wish to address this issue.

KEYWORDS: (5–8 keywords, check in the term bank if necessary).

Contents

Figures

Tables

1 Introduction

A study undertaken by the University of Catania on the Cyclades islands, as well as a subsequent report by the International Union for Conservation of Nature and Natural Resources (IUCN), has concluded that the Mediterranean Sea is among the most contaminated bodies of water worldwide. It is estimated that 1,178,000 tonnes of plastic have accumulated there, including 7% of global microplastics, making it one of the most critical marine areas in terms of environmental impact (Grasso, M. G., n.d.).

It is estimated that 560,000 kilograms of plastic are disposed of in the ocean each year, which is equivalent to the disposal of 34,000 half-litre bottles every minute. A negligible proportion of this plastic, approximately 1%, is retained on the ocean's surface. in the seabed.Furthermore, in the interview conducted by Luna Esposito, it is narrated that plastic, even if it is not there and hides in different forms, only 1~% remains on the surface, the return is in the seabed.A particularly harmful substance is persistent toxic waste (PFAS).These are very toxic and persistent over time: for example, food containers or clothes. These substances are referred to as 'eternal contaminants' due to their inability to degrade and accumulate, thereby posing a significant threat to the health of the ecosystem.(Alessi et al., 2018) A concern arises from the presence of these substances within marine organisms consumed by humans, with levels detected reaching up to 100 times higher than European standards.(Alessi et al., 2018)

The impact on human health is multifaceted, with one salient issue being the increased resistance to antibiotics due to the presence of microplastics in food sources. A recent Italian study demonstrated a correlation between microplastics present in fatty deposits within arteries and an elevated risk of cardiovascular events, such as heart attacks and strokes. (Garancini,2024)

Moreover, the Mediterranean Sea is among the most contaminated on the planet, with an abundance of plastic. The semi-enclosed geography of the Mediterranean Sea and its strategic commercial position result in heavy traffic, while fishing activities contribute to pollution. It is estimated that there are more than 3,000 billion microplastic particles in its waters, making it the most contaminated sea in the world.(Landrigan et al.,2020)

As the World Wide Fund for Nature (WWF) announced in a recent communiqué, as many as 87% of the monitored areas of the Mediterranean Sea are afflicted with pollution problems, primarily related to toxic metals, industrial chemicals and plastic waste. In particular, plastic constitutes 75% of marine litter. (WWF Italy, 2024)

The environmental and economic consequences of plastic use are significant. In 2025, the health costs associated with plastics in the United States alone exceeded $1 trillion, including expenses related to the treatment of diseases and disabilities. Furthermore, the production of greenhouse gases by plastics results in additional costs of approximately $341 billion. And actions to counter this are estimated to cost about 0.5 % of the more global Enel 2040 (Barbanti & Bianconi, 2024).

The fishing sector has been particularly impacted by this issue. Historically, individuals who brought waste ashore from the sea were subject to fines. In response, members of the public mobilised while awaiting the enactment of legislation, leading to the establishment of a dedicated waste disposal facility for fishermen. Many of these initiatives have been implemented by Ogyre.

Ogyre is a global enterprise that, since 2020, has been providing fishermen with equipment and financial compensation to facilitate the collection of waste, thereby enabling them to fulfil their mission to combat plastic pollution.

As reported by Stella Lauro (sustainability manager at Ogyre, who is active in projects in the different ports and working with fishermen), the most significant difficulties are those associated with waste management from a legal perspective. Although there is no paucity of fishermen's turns, the primary issue is ascertaining the responsibility for the disposal. At the present time, the issue appears to have been resolved, as the waste fished out of the sea is classified as urban waste. Nevertheless, there are still problems. Ogyre is attempting to establish a framework to address these issues.

In 2022, the Italian parliament passed the LEGGE SALVAMARE . The purpose of this law, as outlined in Article 1, is twofold: firstly, to contribute to the restoration of the marine ecosystem and the promotion of the circular economy, and secondly, to raise public awareness for the dissemination of virtuous behavioural models aimed at preventing the abandonment of waste at sea, in lakes, rivers and lagoons, and the proper management of such waste. . (*Gazzetta Ufficiale della Repubblica Italiana*, General Series, No. 134., May 17, 2022)

This means that any waste collected by fishermen or ships is considered the same as waste from ships. This means that fishermen can collect waste at sea and store it temporarily (ReteAmbiente,2022)

This means that fishermen can bring in waste without being registered in the National Register of Environmental Managers and without risking fines.

As Lungard's study at Boston College highlights, the entire population is susceptible to the issue, however, the demographic most impacted are those residing on islands and those whose livelihoods depend on fishing. Consequently, their well-being is inextricably linked to the health of the sea (Boston College, 2024).

It is evident that contemporary literature is predominantly focused on the challenges afflicting the marine environment. In this regard, numerous sources have been cited that not only analyse the issues posed by plastic and other pollutants, but also explore the available solutions.The present-day adoption of the circular economy model by numerous corporations is indicative of a growing inclination towards sustainable supply chains.

The recovery of 100 per cent of a product involves the minimisation of waste that would otherwise pollute the environment, and the reuse of end-of-life products. This phase is critical for companies because product remanufacturing accounts for 85 per cent of costs. (Creazza et al., 2021)

In particular, many of these practices, although sustainable from a theoretical point of view, can also have a negative impact on the environment. Furthermore, the costs can be high and can also have an impact from an environmental point of view

This study seeks to address this issue, with a particular focus on the

LCA of best practices used for the recovery and reuse of waste materials in the Mediterranean Sea.

The central research question guiding this study is as follows: How do different practices for recycling polluting marine waste compare in terms of environmental impact, as assessed through life cycle analysis (LCA)?
And what factors influence the choice of a particular method?
Furthermore, this research question will be explored through a series of interviews with multiple companies in the industry, including Seaqual. I also had the opportunity to extract theoretical material from Seaqual.
To this end, the study will draw upon existing research in the field, with a focus on analysing models of the circular economy and the triple bottom line. The latter has recently undergone a resurgence in interest, largely due to its misinterpretation by corporate entities.
The analysis will also encompass the various recovery and reuse methodologies employed by select companies, utilising case studies to illustrate pertinent points. The case studies will include like a said before Seaqual,a Spanish parent company specialising in yarn materials, which utilises a 20:80 ratio of reuse in new products.
The objective of this analysis is to ascertain the most efficacious methods from a cost point a view and from a emission point of view.

2 Literature review

In recent years, the focus on more sustainable production practices has led to growing interest in analytical tools such as Life Cycle Assessment (LCA) and theoretical models such as the Circular Economy (CE). LCA has established itself as a fundamental methodology for assessing environmental impacts throughout the entire life cycle of a product or service, providing an objective framework for strategic and operational decisions. At the same time, CE represents a paradigm that aims to overcome the linear “take-make-dispose” model by promoting the reuse, recycling and regeneration of resources. However, the scientific literature highlights several issues related to the practical implementation of these approaches. Among the critical aspects that have emerged are methodological difficulties in data collection and standardisation, as well as limitations in the comparability of LCA studies. Furthermore, the translation of CE principles into concrete business strategies is often hampered by regulatory, cultural and market barriers. The research highlights the lack of shared indicators to effectively measure circularity and environmental impacts. Despite the critical issues that have emerged, the integration of LCA and CE is considered a promising direction for supporting the ecological transition.

2.1 Pollution in Mediterrenean sea

The Mediterranean Sea has historically been home to numerous civilisations, yet it is now considered to be among the most polluted bodies of water worldwide, with plastic constituting 95 per cent of the total pollutants. This phenomenon can be attributed in part to the fact that Europe is a major producer of plastic, with annual production ranging from 150 to 500 thousand tonnes (WWF Italy, 2018). This substantial accumulation of plastic is also attributable to its tendency to adhere to the sea bed, thereby impeding effective water recirculation and giving rise to substantial accumulations of plastic, which account for between 5 and 10% of global macrolastics in the Mediterranean Sea (E.ON Energia, n.d.).

However, a particularly salient fact is that the concentration of microplastics in the Mediterranean is 4 times higher than that found on plastic islands in the Pacific (WWF Italy, 2018).
One of the primary issues engendered by pollution, particularly that of plastic, is the threat it poses to marine ecosystems. The presence of large chunks of plastic has been shown to injure and strangle hundreds of animal species, including protected species, thereby endangering the entire ecosystem, both marine and terrestrial. This phenomenon also exerts a significant impact on human health (WWF Italy, 2018).

Moreover, the formation of plastic islands has been observed in the vicinity of Corsica and the island of Elba. At present, these islands are cyclical in nature, i.e. dependent on currents. The project, which was supported by the European Space Agency, united space companies and research centres from six states in a single team that examined satellite images obtained over a period of six years. Surveillance of the Mediterranean region was conducted at three-day intervals, with the objective of identifying waste materials. Utilising the Sentinel-2 satellite (a component of the Copernicus programme), the team identified numerous waste accumulations ranging in size from a few hundred metres to 20 km. The primary plastic accumulation on the island of Strova in the Tuscan region is visible afloat, with the majority of it situated on the seabed (Mezzetti, 2025, January 12).

The problem with plastic is related to its chemical nature: plastic is a material that persists over time and is not biodegradable. Over time, it breaks down into small particles called microplastics.

Visible pieces of plastic can cause problems for animals by entangling them or causing damage to ecosystems. Microplastics, on the other hand, pose a hidden and insidious threat: because they are very small and barely visible, they can be ingested by other organisms, which in turn are ingested by other organisms, resulting in contamination throughout the food chain. (Perin, 2022.) The European Union's core definition of microplastics is as follows: "Microplastics are tiny pieces of plastic material, usually less than 5 millimetres". (European Parliament, 2018).

These can be categorised into two distinct classifications; The primary microplastics are released into the environment as small particles, for example from tyre abrasion. The secondary microplastics are created by the abrasion and degradation of polluting materials already present in nature, such as fishing nets, bottles and plastic bags. This category accounts for approximately 70% of the total microplastic presence. '. (European Parliament, 2018.)

2.1.1 Ghost gear

These include nets, lines and other fishing gear that are abandoned or accidentally lost at sea. The consequences of this include the death of fish, corals and damage to Posidonia and various other marine species (Borelli, 2025). This is a threat that, in addition to plastic, affects the Mediterranean in a 'passive' way. As reported by Bruno Borelli, approximately 2% of the marine area of Portofino, Italy, was surveyed, yielding a total of 950 organisms from the 91 gears that were surveyed. A more precise calculation suggests that the impact of the 1,800 gears may potentially affect approximately 18,000 organisms. (WWF Italia, 2025, February 18)

Moreover, the study 'Global estimates of fishing gear lost to the ocean each year' provides an analysis of the number of fishing nets and materials lost by fishermen during their activities. It is estimated that approximately 2% of fishing nets and more than 25 million hooks and traps are lost at sea. (Richardsonet al., 2022)

This statement underscores the gravity of the repercussions that fishing waste exerts on the marine ecosystem. As demonstrated in Table 1, a significant proportion of fishing equipment is composed of plastic materials, a factor that is intricately linked to the broader issue of plastic pollution. Notably, fishing nets are typically composed of nylon or lolyamide, polyethylene terephthalate, and polypropylene (PP). (Hall and Richardson, 2023, p. 7) The selection of these materials is driven by their inherent characteristics, namely their lightness and durability.

Table 1. (Fishing gear and material)

Gear/tool	Plastic materials	Wood	Lead	Iron/steel/aluminum	Cement
Trammel net	x		x		
Drift net	x				
Pots	x	x			
Trawl nets	x		x	x	
Dredges	x			x	
Sinkers			x	x	x
Ropes	x				

However, the longevity of fishing nets may be compromised if they become Ghost Gear. As discussed in previous chapters, plastic that persists over time undergoes a degradation process, releasing microplastics into the environment. Nylon and polyamide (PA) are recognised as plastics that exhibit high resistance to wear and impact (Realplex, n.d.). However, it should be noted that the production of these materials necessitates the utilisation of non-renewable energy sources, a factor that can exert a substantial environmental impact. The dispersion of these plastics into the oceans has the potential to harm aquatic life and contaminate the food chain, with potentially irreversible consequences. (Plastic Mold,n.d.)

However, modern fishing equipment is typically composed of a multitude of polymer and other materials, including wood and metal, which can be amalgamated in numerous combinations.

2.2 From collection to recycling

A thorough analysis of the aforementioned issues reveals that the problem cannot be understated or eliminated in a short timeframe.

Consequently, the primary objective of numerous nascent enterprises appears to be the identification of a viable opportunity within this predicament.

A prominent Mediterranean-based start-up, Ogyre, exemplifies this trend, having been involved in the collection of marine waste for an extended period.

Their approach, termed 'Fishing for Litter', involves the deployment of specialized vessels equipped with state-of-the-art litter collection technology. This initiative involves providing financial incentives to local fishermen to collect litter during their fishing expeditions and deliver it to designated partners for proper waste disposal. (Ogyre, n.d.)

In a concise interview with the CEO and co-founder, Antonio Augeri, it was reported that Ogyre is prioritising waste collection without a concurrent emphasis on waste reuse. Furthermore, he notes that the collection process is increasingly taking place in developing countries.

This is attributed to the projection that by the year 2050, Asian rivers could bear between 34 and 46% of the world's plastic load discharged into the sea (Ogyre, n.d.). This poses a significant challenge, but it can be mitigated by increasing collection points and reducing consumption, which has the potential to decrease this scenario by 40% (Bergmannet al., 2015).

A significant number of companies depend on external partners for the regeneration of waste, while others undertake this process internally. This encompasses the entire spectrum of waste management, from its collection to its recycling. SEAQUAL, a company that excels in both waste collection and the production of recycled yarn, is a prime example of this. Its SEAQUAL®YARN is a highly sought-after product, being purchased by companies across diverse sectors, including the automotive and watchmaking industries. (SEAQUAL INITIATIVE, 2025, 6 March)The process of producing SEAQUAL® YARN is fundamentally comprised of five distinct stages.The initial stage is known as Collection, wherein a number of clean-up initiatives (such as those involving fishermen, local authorities, and NGOs) collaborate to collect waste from marine areas.

Subsequent to the collection of waste, instead of its disposal in bins, it is transferred to the Sequal initiative, where phase 2, the sorting of the waste, takes place (TWOTHIRDS, 2023, June 30).

Of the total 400 million tonnes of waste, only 9% is recyclable, with 14 million tonnes being disposed of in the sea. Of the 14 million tonnes, 20% is attributed to fishing and shipping activities, with the remainder stemming from land and transported into the sea via rivers, wind, and human activities (sources: Seaqual materials by me).
Following the collection of these materials, they undergo a thorough sorting process. The marine plastic is then shredded and subjected to a rigorous washing procedure. This is undertaken to ensure the safety and quality of the materials. This stage is referred to as "Flakes" and comprises four additional stages.

- Shredding
- Cold wash
- Hot wash
- Drying

In the fourth phase, the material undergoes transformation. The plastic flakes undergo a process of repeated melting, resulting in the formation of a primary material, designated as SEAQUAL® MARINE PLASTIC. This material can be utilised in the injection moulding process to create a variety of products, including mop handles, bumper paddles, watch clocks and glasses.
The final stage of the process involves the creation of the recycled Seaqual yarn. This yarn is constituted of 10% Seaqual marine plastic, i.e. plastic recovered from the oceans and obtained by the aforementioned processes, with the remaining 90% comprising waste collected on land. It is important to note that marine waste is more difficult to recover and process.

2.3 The circular economy Model

In recent decades, mass consumption has become unsustainable. Consequently, there has been an attempt to replace the end-of-life model with the concept of restauration. This involves a transition from the use of renewable energy to the elimination of toxic substances that hinder recovery, as well as a design that favours recovery methods. (Ellen MacArthur Foundation, 2013, p. 07)The circular economy model is predicated on the need to reduce the environmental impact and to move away from the conventional

linear economic model. This model is characterised by the logic of supply, use and waste.(Geissdoerfer et al., 2017) The low level of resource prices, relative to labour costs, has also created the current wasteful system of resource use. The reutilisation of materials has not been a significant economic priority. Consequently, this has favoured linear economic models where recycling was not the primary focus. The prevailing economic model, as articulated by the Ellen MacArthur Foundation (2013, p. 15), encompasses the three sequential phases of 'take', 'make' and 'dispose'.
Moreover, energy consumption is notably higher when recycling or incinerating is the preferred option. Conversely, a more circular approach would result in substantial energy savings. One such example is the reuse of packaging. (EllenMacArthur Foundation, 2013, p. 16)

In circumstances where resources are abundant and inexpensive, this model could be optimal and efficient, meeting demand and yielding excellent results.
However, it is important to note that this model is predicated on the throwaway principle, and as such, it is approaching a point of unsustainability.
The observed rise in population, in conjunction with the limited availability of non-renewable resources, has been demonstrated to be incapable of meeting current demand. (Geissdoerfer et al., 2017). The Circular Economy – A new sustainability paradigm) pag circa 30 ma non lo dice
In addition to the demographic fact that the population is expected to reach approximately 10 billion by 2050, this poses a significant risk to companies, which are likely to experience a considerable increase in commodity prices, thereby impacting their profits (Ellen MacArthur Foundation, 2013, p. 18).
It is therefore evident that an alternative model is required; this is the circular economy. The European Union provides the first definition of the term, establishing it as a ”model of production and consumption that involves sharing, lending, reusing, repairing, reconditioning and recycling existing materials and products for as long as possible”.(European Parliament, 2023)

This strategy is intended to promote an expansion of the life cycle of products, with a view to reducing waste entering the environment.

2.3.1 Principles of circular economy

‘The circular economy has drawn a clear distinction between the consumption and use of materials’. (EllenMacArthur Foundation, 2013)

In essence, the paradigm of the circular economy has precipitated a shift in the manner in which retailers and manufacturers perceive themselves. In accordance with the principles of the circular economy, they function as service providers, offering 'the use of the product' rather than the consumption of the product. (Ellen MacArthur Foundation, 2013)

One of the approaches to the circular economy is the 3Rs: reuse, reduction, recycling. (Muthu, 2019).

The term 'reuse' is employed to denote the act of utilising components or objects once more in a manner that facilitates the reutilisation of said components, or alternatively, the substitution of existing components with new components. The term 'reduce' pertains to the processes and methodologies employed to minimise the generation of waste(Muthu, 2019). The term 'recycle' is employed to denote the process of recovering any type of pollutant material that can be recovered during the production process(Geisendorf et al., 2018).

The origins of this concept can be traced back to the 1970s, and it has undergone a process of evolution over time. However, it remains an outdated concept in certain contexts. (Geisendorf et al., 2018).

For instance, in the context of reuse, there exists the issue of individuals who are reluctant to purchase a product that has previously been used by another person. (Geisendorf et al., 2018)

In this particular instance, the aforementioned principle does not apply to the subjects in question.

Moreover, in the magazine maccaleger, the principles of the 3Rs are articulated with greater breadth and clarity.

The concept in question elucidates the necessity of designing waste-free, a principle that encompasses the non-use of toxic substances in order to minimise environmental impact, and the design of materials that can be reused. (EllenMacArthur Foundation, 2013, p. 07) Furthermore, the transition to renewable energy sources is instrumental in reducing pollution. According to the European Union, the target is to use 45% renewable energy sources by 2030. (European Parliament., s.d.).

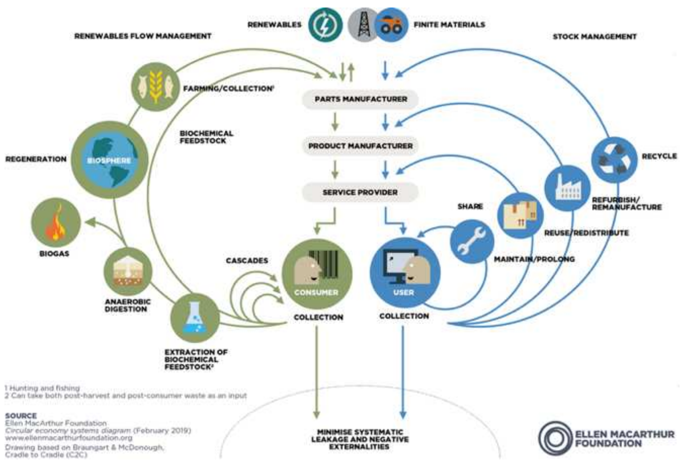
Furthermore, Michael Braugant expounds on the notion that diversity frequently fosters adaptability to diverse environments, thereby enhancing the sustainability and weatherproofing of products. This phenomenon has been somewhat diminished in the context of the industrial revolution(Michael Braungrath, 2017).

It is imperative to acknowledge that a process which embodies the fundamental principles of a circular economy is predicated on the utilisation of waste as a resource.

As previously mentioned, it is imperative to minimise the impact of the system, and the most effective method of achieving this is through the reuse of materials that would otherwise be discarded. This approach is encapsulated by the principle of 'waste is food', signifying the reintegration of waste, including biological waste, back into the biosphere, in accordance with the preceding concepts.

In order to facilitate comprehension of this latter concept, it is beneficial to employ the butterfly diagram as a visual aid. The butterfly diagram shows how the circulatory economy and material flow works in this system. (Goffi,2023, p.12)

In this image(see figure 1) we can see 2 hemispheres. Biological lemisphere and the technical cycle.



Figures 1. (Ellen MacArthur foundation, 2023)

Biological Lemisphere "which is for materials that can biodegrade and safely return to the earth". (Ellen MacArthur Foundation, 2022) describes the process by which materials return to the soil and can contribute to the creation of new nature. (Ellen MacArthur Foundation, 2022)

Conversely, the technical cycle encompasses products that are utilised in lieu of being consumed.

These products are subject to reuse through a series of processes including reuse, repair, remanufacturing, and recycling. (Ellen MacArthur Foundation, 2022)

It is imperative that each product is designed with the intention of reuse in mind from the outset, as this would ensure that products intended for reuse are already in the early stages of the product life cycle. (Ellen MacArthur Foundation.,2022)

In this context, it has been demonstrated that the internalisation of processes by companies is a superior strategy for the optimisation of circularity, thereby affording them a competitive advantage characterised by the enhancement of profitability and sustainability.(Mingotto,2023)

2.3.2 From blue economy to blue circural economy

So far, we have examined the concept of circular economy as a whole. The present study, however, is focused on the analysis of the LCA (Life Cycle Assessment) of waste in the Mediterranean Sea.

In this context, it is imperative to emphasise the significance of circularity models within the maritime sector.

A concept that is frequently mentioned in this context is that of the blue economy.

The following preliminary definition can be proposed: “The Blue Economy includes all economic activities related to the seas and oceans, operating directly in or near the marine environment” (Pictet Asset Management, 2024).

The necessity for the preservation of the world's oceans is also derived from European institutional requirements. These requirements are outlined in the 2030 Agenda for Sustainable Development, which introduces Sustainable Development Goals (SDGs). The SDG with the specific objective of addressing this issue is SDG 14 that aims to “Conserve and sustainably use the oceans, seas and marine resources for sustainable development” (United Nations, n.d.) but in addition to the 2030 agenda there are other institutional initiatives including the Mediterranean Strategy for Sustainable Development 2016-2025 “which provides an integrative framework for all stakeholders to translate all objectives at regional, sub-regional, national and local level in the Mediterranean Region" (United Nations Environment Programme, n.d.)

The MSSD (Mediterranean Strategy for Sustainable Development) is structured into six objectives, each of which encompasses groups of SDGs that are suitable for that particular objective. The primary focus of the targets is on the Mediterranean coastal zones, with particular emphasis on the first concern. “Ensuring sustainable development in marine and coastal areas” recalling SDG 15 and number 6 that are particularly concerned with the transition to the blue economy” (United Nations Environment Programme, n.d.). In this image down here (see figure 2) you can see the rapresentation of the sdg’s regarding the prodetection of the envroment.

MSSD Objectives	SDGs		
1. Ensuring sustainable development in marine and coastal areas			14 LIFE BELOW WATER
2. Promoting resource management, food production and food security through sustainable forms of rural development	2 ZERO HUNGER	15 LIFE ON LAND	6 CLEAN WATER AND SANITATION
3. Planning and managing sustainable Mediterranean cities		11 SUSTAINABLE CITIES AND COMMUNITIES	7 AFFORDABLE AND CLEAN ENERGY
4. Addressing climate change as a priority			13 CLIMATE ACTION
5. Transition towards a green and blue economy	8 DECENT WORK AND ECONOMIC GROWTH	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
6. Improving governance in support of sustainable development		16 PEACE, JUSTICE AND STRONG INSTITUTIONS	17 PARTNERSHIPS FOR THE GOALS

Figure 2 (Unep, 2026).

Returning to the definition of the “blue economy”, it can be said that it is only one possible way of analysing the concept of protecting the seas and oceans. In order to explore this concept further, further terminologies by which this phenomenon can be defined are proposed below.

” Some of the most commonly used terms to refer to marine economic activities include: Marine Economy, Ocean Economy, Green Economy, Circular Economy, Blue Growth and Blue Economy”(Gasparini, 2023, p. 6)

As shown in the Venn diagram below, which illustrates four economic dimensions, all these areas have as a common goal the preservation and development of the oceans.

The concepts under consideration present considerable similarities, however, in the different economies, distinctive themes emerge. In fact, there is a transition from risk and marine integration, within the marine economy, to harnessing sea power for economic development and innovative technologies. (Gasparini, 2023, p. 8)

The European Union has begun to attach increasing importance to the maritime ecosystem and to consider the actions necessary to preserve it. This includes the proper management of resources, promoted through circular models (Carta, 2024 pag 476), i.e. comparative analysis between marine economy,blue economy blue growth and ocean economy (see figure 3).

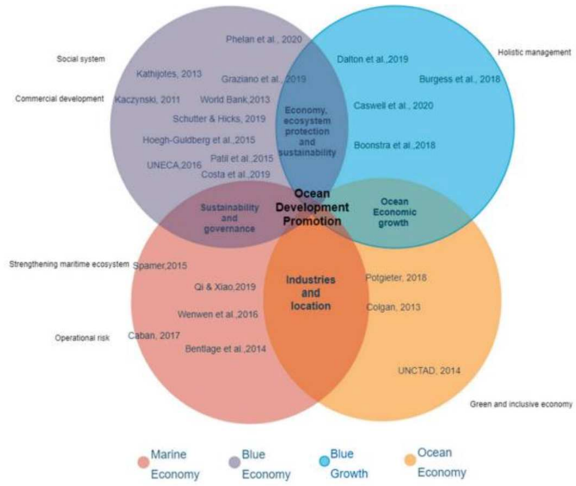


Figura 1. Analisi comparativa tra Marine Economy, Blue Economy, Blue Growth e Ocean Economy (Euromesco Policy Report)

Figure 3 (Universita Ca'Foscari,2024)

An example applicable to such theories is the concept of the blue circular economy. "Blue Circular Economy (BCE) is a transnational project that supports the transformation of discarded fishing gear and marine plastic waste into recycled products." (European Commission, 2020 November 9)

This project was initiated and continues to develop in the northern seas (European Commission, 2020 November 9), Nevertheless, this project has the potential for replication on a small scale. Indeed, Seaqual is an example of a company that has adopted this business model in the independent sector and in the Mediterranean Sea.

2.3.3 Life Cycle Assessment (LCA)

As previously discussed, the correct utilisation of resources is paramount. The circular economy advocates for their respect and subsequent reuse.

However, the question remains: how can we ascertain the sustainability of any given practice, or determine the relative merits of different approaches? The present study aims to explore the potential of models to assist in this decision-making process.

This is the case with Lyfe cycle assesment, which is defined by the International Organisation for Standardisation (ISO) as ”compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”. (International Organization for Standardization, 2006).

It therefore analyses and evaluates the entire life cycle of a product and then determines its real impact. This analysis has two main areas of application: business management and socio-economic land management.

The results facilitate the decision-making process for companies and governmental bodies concerning product development and the most environmentally critical steps in their implementation, allowing for the identification and correction of any issues (Gori, 2016, p 52).

A clearer definition of it is given by the Ellen Meccarthur foundation, which defines it as”a process for evaluating the environmental impacts of a product or service over the course of its entire life” (Ellen MacArthur Foundation, 2022, April 8)

The outcome is that the impact of a product is not only determined by the materials used, but also by how it is collected, processed and, in particular, reused.

In cases where the materials used are “sustainable” but the processes employed are not, it is clear that the very nature of the product, designed to be sustainable, is compromised.

The lack of proper attention to the product's life cycle can sometimes lead to the practice of green washing “the intersection of two firm behaviors: poor environmental performance and positive communication about environmental performance” (Delmas & Burbano, 2011 pag 4).

The utilisation of LCA can be evaluated through a comparison of the choice between a paper bag and a plastic one.

Upon initial observation, it may be perceived that a paper bag exhibits a lesser degree of impact in all respects. However, this is not universally applicable, depending on the intended application of the material.

An analysis of the production data reveals that the utilisation of 58 gallons of water is required to produce 1,000 plastic bags, while 1,004 gallons of water are utilised to

produce an equivalent quantity of paper bags. The manufacturing process for plastic bags utilises a significantly lower quantity of energy and non-renewable resources when compared with the production of paper bags (The ULS Report, 2008, March 28, P. 4)
The qualitative table (see) highlights various aspects that end consumers and companies involved in business strategies could consider to guide their decisions.
Plastic bags have undoubted advantages, including the possibility of being reused for the production of further products, in line with the principle of the “circular economy”. Other bags, on the other hand, are preferable due to their greater biodegradability, which in turn reduces the impact on the marine ecosystem.

Bag type	Storage space required	Reusability	Energy demand for production	Marine risks	Biodegradability
Plastic	Lower	Higher	Lower	Higher	Generally lower
Paper	Higher	Lower	Higher	Lower	Generally higher

Table 2. Comparison between papar and platic bag (appropedia, 2010).

In conclusion, the LCA facilitated comprehension of the critical factors pertaining to these two materials. It was determined that the utilisation of a disposable bag is preferable to a plastic one, as it results in a reduced environmental impact.
” the issue is not paper or plastic, but rather finding ways to reduce, reuse, and recycle both of them – in that order” (The ULS Report, 2008, March 28, P. 4)

2.3.4 Problems and limitations of LCA

Like any model, the LCA has limitations. Therefore, it may only be useful for short-term planning and may discourage long-term changes. For example, some studies conducted by LCA have shown that the way forward for improving the energy efficiency of heat engines is more promising than the transition to electric cars (Ellen MacArthur Foundation, 2022, April 8)

This figure, however, has been questioned by some studies and government bodies. In fact, emissions during the entire life cycle of an electric car are significantly lower (U.S. Environmental Protection Agency, 2021, March 4)
A further limitation of the present study is that it considers easily measurable data, such as CO_2 emissions, while omitting data on more challenging to retrieve issues, such as plastic pollution. Furthermore, it frequently employs metrics that are assigned to it for evaluation. (Ellen MacArthur Foundation, 2022, April 8)

The Ellen MacArthur Foundation has also identified several ways in which the LCA can be used correctly. A prospective analysis is initiated with the aim of improving specific areas of the company. Alternative scenarios are also considered, including the use of different energy sources. These are compared with similar business models in order to identify the most effective and sustainable solutions. It is imperative that the data used is reliable and trustworthy. (Ellen MacArthur Foundation, 2022, April 8)

2.4 LCA related to waste recovery practices at sea

It has been demonstrated that the LCA is a useful tool for identifying which process in the life of a product has the greatest impact.
The present study will concentrate on the environmental impact of different recycling practices of materials frequently encountered in the sea.
As previously documented, the presence of plastic barrels and fishing nets in the sea has been frequently observed.
"The main recycling processes available for fishing gear include primary and secondary recycling (mechanical recycling), tertiary recycling (chemical recycling and thermal conversion) and quaternary recycling (energy recovery)" (Barbanti & Bianconi, 2024, p. 58).
However, sometimes it is not possible to recycle 100% of the materials due to the poor condition of the waste or the presence of toxic materials. The type of recycling also depends on the type of polymer in the material being recycled (Barbanti & Bianconi, 2024, p. 58).

Furthermore, a relevant aspect to consider when analysing the impact of a specific operation is the location of the different project phases. A significant example is the plastics sector, which faces significant logistical challenges, including waste management, which often nullifies the benefits of a circular approach (Barbanti & Bianconi, 2024, p. 36)

2.4.1 Recovery, classification and recycling of fishing gear at sea

Returning to the recovery and reuse of waste at sea, fishing nets outnumber plastics but According to Richardson, “nearly 2% percent of all fishing gear enters the world’s oceans each year; this amounts to more than 25 million pots and traps, 75.049 km2 of purse seine nets, 218 km2 of trawl nets, and 739.583 km of longline mainlines” (Richardson et al,2022, p.3). Notwithstanding, this demonstrates a substantial effect on the ecosystem. There are 2 categories of fishing nets. Le “Abandoned, lost or otherwise discarded fishing gear (ALDFG) e end-of-life fishing gear (EOLFG), and are generally collected by fishers” (Sala & Richardson, 2023, p. 4)

The first of these is defined as 'ghost gear', a term previously introduced in earlier chapters. The second is defined as 'end-of-life nets', which are nets that are returned to collection centres by the fishermen themselves.

One of the biggest differences between the two is the ease of recycling. In the ALDFGs, it is much more difficult to recycle because the materials that have been left in the sea without proper care are irrecoverable. In contrast to EOLFGs, which, being brought back ashore by fishermen, are better preserved. (Sala, & Richardson, 2023, P. 5)

Because of this, the vast majority of fishing gear recycling companies almost exclusively recycle EOLFG.(Sala & Richardson, 2023, Pag 5)

Fishing equipment is generally composed of polymeric materials, including polyamide (PA), nylon, polyester (PES), polyethylene (PE) and polypropylene (PP) (Barbanti & Bianconi, 2024, p. 57).

In order to facilitate the recycling process, fishing nets are prepared through a series of procedures. Firstly, they are divided into multiple sections to enhance their portability.

Subsequently, they undergo a cleaning process to remove non-recyclable materials, such as lead, which are then segregated from the rest of the net (Barbanti & Bianconi,).

2.4.2 Practices Adopted

Within the domain of waste recycling, particularly in the context of marine environments, as previously referenced, plastic occupies a significant proportion of the materials identified, primarily attributable to its distinctive characteristics that facilitate its utilisation.

Consequently, a significant degree of similarity has been demonstrated between the recycling processes of plastics and fishing nets.

The following four categories are under consideration: ”The four main recycling processes summarized include primary and secondary (mechanical), tertiary (chemical) and quaternary (energy recovery) recycling schemes and technologies”(Sala e Richardson, 2023, p. 11)

Primary recycling, which “involves the re-introduction of clean scrap of single polymer to the extrusion cycle in order to produce products of the similar material, is commonly applied in the processing line itself but rarely applied among recyclers, as recycling materials rarely possess the required quality”. Hopewell et al., 2009, p. 2626.

Secondary recycling is a process in which a greater variety of plastic materials can be utilised. These materials are subjected to a process of shredding. This phenomenon, whereby a higher quality is transformed into a lower quality, is referred to as "downcycling". (Sala e Richardson, 2023, p. 12)

“Currently, the preferred route for handling plastic materials is the secondary route, the stages of which are divided into: separation and sorting, packaging, washing, grinding and finally pelleting “ (Squadrone, 2023, p. 17)

The only drawback of this process is that it results in a loss of the material's initial quality. This process is also referred to as "downcycling". (Sala e Richardson, 2023, p. 12)

Tertiary recycling also known as chemical recycling “is employed for these technologies since the polymer’s chemical structure changes through these processes”. (Sala e

Richardson, 2023, p. 15) and allows the polymers to break down and recover the original composition of the plastic, which can then be used as new.

(Simboli, n.d., p. 22) In this way, a higher quality is maintained compared to mechanical recycling, due to depolymerisation. (Sala e Richardson, 2023, p. 15).

The last method of waste recycling is called “quaternary recycling” or “energy recovery”. Unlike the previous methods, this mode does not produce new products from waste, but generates new sources of energy (Sala e Richardson, 2023, p. 18).

“By definition, Energy recovery implies burning waste to produce energy in the form of heat, steam and electricity”(Al-Salem et al., 2009)

This process is used for waste that cannot be recycled by other methods and preserves the integrity of the coastline by converting it into energy resources, such as fuels.

As discussed before, there are several applicable practices. It would be advisable to determine which of these are most beneficial for businesses, considering both environmental and economic aspects.

Therefore, from a practical point of view, the technology that needs further development is that of quaternary recycling, as it involves excessive costs from an economic point of view, thus limiting access to more advanced technologies that could help reduce environmental impact. (Sala e Richardson, 2023, p. 18)

The issue of cost and energy consumption is also pertinent to the development of chemical recycling, which, despite its increased popularity, is faced with the same challenges as quaternary recycling. (Sala e Richardson, 2023, p. 18)

According to Schneider, mechanical recycling followed by quaternary recycling are the least impactful considering the whole LCA (Schneider,et al., 2023)

The objective of this study is to verify the validity of the proposed theory, assessing the presence of possible changes and analysing the case study of the SEAQUAL company. The analysis will focus in particular on the environmental impact and costs associated with the different practices.

3 Research met.

This section will analyse the method used to collect information, as well as examine the ways in which the information was collected.

3.1 Case indices and summaries of court rulings

According to Eriksson & Kovalainen “All research methods are in close connection to research philosophy and to the ways it is possible to bring forward new knowledge through research”. (Eriksson & Kovalainen, 2008, p. 11)

”The term research philosophy refers to a system of beliefs and assumptions about the development of knowledge” (Saunders et al.,2024, p. 131).

Using this definition, we can start to understand how to plan an approach to answer the research question. We can do this by looking at the world around us to see the good and bad points of using different research methods.

For my research, the best approach is positivist philosophy. This is because it is based on the method of a natural scientist. This method allows us to identify and analyse a phenomenon in an objective way. (Saunders et al.,2024, p. 145).

To speak of objectivity, we can use the word ‘objectivism’, which has to do with the concept of positivism.

“Objectivism incorporates the assumptions of the natural sciences, arguing that the social reality we research is external to us and others” (Saunders et al.,2024, p. 136)

Objectivism is a philosophy that emphasises the existence of social reality and asserts that, irrespective of the presence of other subjects and their concomitant opinions, interpretations or perceptions, the world remains as it is.

The underlying premise of this approach is that the analysis of numerical data is inherently independent of the presence or perceptions of other human beings. The only factor that has the capacity to exert influence over this process is the work of the companies, or, at most, my perception of the results obtained. However, in order to attempt to prevent the opossums from exerting an influence on the results, it is necessary for me to maintain a neutral position. (Saunders et al.,2024, p. 147)

A study, following the positivist theory, is based on finding theories to develop hypotheses that will be confirmed or proven false and from this one can develop a further hypothesis. (Saunders et al.,2024, p. 147)

Positivism can be categorised into two distinct approaches: the deductive and the inductive. The deductive approach is initiated with the formulation of a theory, which is then substantiated or refuted based on the analysis of data. Conversely, the inductive approach entails the development of a theory from the data.

The approach adopted in this research is the deductive type, since, while starting from a basic theory that provides a general view of what is already known about the subject, one proceeds to formulate hypotheses that will subsequently be verified through the analysis of the data collected.

As was highlighted in Chapter 2.3, the mechanical recycling method appears to be the most convenient for companies. The hypothesis will be verified or revised through the collection and analysis of data.

The method of data collection is of crucial importance, and in the case of this paper, both methods will be employed.

Two distinct types of research design can be delineated: Qualitative and quantitative. The quantitative approach is predicated on the utilisation of statistical measurement systems to identify a multitude of variables. These variables are then subjected to comparative analysis in order to arrive at a solution. (Saunders et al.,2024, p. 184). It is often associated with positivist thinking (Saunders et al.,2024, p. 183), but it is not always true and it is wrong to associate as a rule that positivism, deduction and a quantitative are always linked.(Walsh et al., 2015, p. 588)

The qualitative method, on the other hand, is often associated with the philosophy of interpretivism, i.e. when the researcher is more interested in a subjective than an objective approach. (Saunders et al.,2024, p. 185).

It can be deduced from this that the researcher must interpret and understand the data he has collected, which are often not available in the existing literature, and thus he

finds himself having to develop new theories applicable to his case. This approach can be ascribed to an interpretivist approach (Saunders et al.,2024, p. 185).
The research method utilised in this study is qualitative. The quantitative approach may offer a more satisfactory answer, as it involves the analysis of numerical data, thereby producing a clearer result. However, due to challenges in obtaining data from companies for reasons of privacy, I opted for the qualitative approach. This allowed me to obtain a more comprehensive perspective and facilitate a more extensive comparison with a greater number of companies.
A qualitative study may be conducted using two distinct approaches: either of which involves the use of a single method of data collection, such as a semi-structured interview, and is termed a mono method qualitative study. The second approach is referred to as a multi-method qualitative study, which involves the utilisation of multiple methods for the collection of data. (Saunders et al., 2024, p. 186).

3.2 Data collection

The data utilised in this research was obtained from semi-structured interviews. In a semi-structured interview, a standardised set of questions is employed to ensure the collection of comparable data from different participants (Saunders et al., 2024, p. 443). However, some flexibility is permitted in the formulation of questions, contingent on the interviewee's responses.
It is evident that semi-structured interviews can be categorised into two distinct types.
Thematic semi-structured interviews are utilised for the purpose of data collection, with the structure of the interview being defined by a series of predetermined themes that are pertinent to the specific research question being investigated.
The format of the interviews is distinctive, being semi-structured. The data is collected through a specific approach.
The merits of a semi-structured interview are twofold. Firstly, it provides a set of standardised questions, yet secondly, it allows for the flexibility to inquire beyond the boundaries of the standardisation. This approach fosters a trusting relationship with the

interviewee, which in turn can yield novel information and perspectives for analysis. Kircher et al., 2022, p. 102).

Furthermore, they place greater emphasis on the interviewee, occasionally enabling them to direct the interview towards topics they deem to be of greater significance (Kircher et al., 2022, p. 102).

The limitations of the semi-structured interview are attributable to the cultural and social context, which has the capacity to engender certain biases.

One such example is the social desirability bias, whereby interviewees are required to report their own attitudes, which may not always accurately reflect their actual beliefs (Kircher et al., 2022, p. 101).

Furthermore, a bias that has the potential to compromise the objectivity of the interviewer is known as the acquiescence bias. This is characterised by the interviewee's automatic agreement with the interviewer, thereby skewing the interview towards a more favourable outcome. (Kircher et al., 2022, p. 101).

Regarding data collection, I managed to conduct five interviews with employees from three different companies. The companies examined and considered were Aquafil, Seaqual and Erion Packaging.

For reasons of confidentiality, the interviewees will not be mentioned by name and surname, but identified by the number “Interviewee n”, up to number 5.

In the case of Seaqual, there were two interviewees who held different positions within the company. The second interviewee works in the commercial area, while the first is mainly involved in the operational side of the company. Given that Seaqual is a Spanish company, the interview was conducted in English. The decision to use English was determined by the fact that Spanish is the mother tongue of our interlocutors and my language skills are not adequate to conduct the interview in Spanish.

At Aquafil, the interviews were conducted in Italian, given that the company is based in Italy and the need to communicate effectively with the interviewees.

Again, the interviews were conducted with two interviewees, both from the company's procurement department. For this section, the interviewees are identified as number 3 and number 4.

The last interview was conducted at a company operating in a different sector from the previous two. Erion Packaging focuses primarily on recycling packaging for the production of paper sheets. The aim of this interview was to compare different methods applied in various business contexts in order to evaluate their performance and identify best practices to be adopted. The Italian engineer interviewed, as the company's manager, provided detailed information on business processes, representing a significant opportunity to understand best practices in the industry. In addition, his expertise provided an opportunity to discuss recycling methods not adopted by his company. This type of information was essential for making a correct comparison of the data and drawing accurate conclusions.
I would like to point out that all interviews were conducted online due to the considerable distance and logistical difficulties.

3.3 Data analysis

In order to analyse the model as clearly as possible and to reach conclusions that reflect the interviews conducted in this paper, the thematic analysis method will be used.
According to Braun and Clarke (2006), thematic analysis consists of six main stages: familiarisation with the data, initial coding, identification of themes, review of themes, definition and naming, and finally report writing. There are several variations of this approach, such as the seven-stage model proposed by Norton (2009). (ECRM, 2022)
An alternative to thematic analysis could have been content analysis.
The decision to proceed with thematic analysis was determined by the fact that its scope of application is more limited than content analysis, which deals with larger data sets.
In the case in question, the analysis of a limited data sample suggests that the optimal choice is thematic analysis. (ECRM, 2022)
Furthermore, thematic analysis is considered a more flexible methodological approach for qualitative research methods, as it is capable of analysing a variety of research models (ECRM, 2022)
The selection of specific themes within this type of research will be essential to ensure a consistent and comprehensive analysis of all interviews.

The refinement of themes and the relationships between them is a crucial step in the analysis, as it allows for the development of testable hypotheses. In order to consider a correlation between themes as effective, it must be subjected to thorough verification. (Mari Pakku, p. 54). The tool used for coding categorisation is fundamental.
In this circumstance, thematic analysis proves once again to be a valuable tool, as the interpretation of data plays a fundamental role.(ECRM, 2022)

4 Findings

In this section, the study will attempt to answer the research question and understand which recycling method is best from an environmental point of view, identifying the factors that influence the choice.
To complete this phase, a series of interviews were conducted with professionals in the recycling sector, both marine and non-marine.
I decided to also consider companies outside the marine sector, as the recycling chain is the same for both marine and non-marine waste.
To analyse the interview data and derive the results, I adopted a coding process that helped me greatly in answering the second part of the research question.
In fact, this chapter will be divided into subchapters covering the key factors identified, from which I will derive a qualitative answer to the best method according to my study.

4.1 Types of recycling and applications

One of the main themes that emerged during the interviews was that the recycling process depends on the end use of the recycled material.
In the field of recycling, the term “waste” can sometimes be inaccurate.
The partecipant number 5, an environmental engineer and General Manager at Erion Packaging, provides the following definition of the term waste ”as a secondary raw material.Industries purchase the material (waste), process it and then produce processed secondary raw materials from it.”
Following this brief introduction, we can now move on to discussing the use of waste.
As is well known, the intended use of these materials is not uniform. Some of them are recycled and subsequently used in paper production, while others are used in the ticketing sector.
Recently, the term “RYCICLE YARN” has emerged, which defines a type of yarn obtained from the recycling of waste.

As already discussed at length in the previous chapters, Seaquel produces its own recycled yarn, obtained through chemical recycling processes. This material is often used in the production of clothing, often by well-known brands. As specified by interviewee number 1, ”Seaqual yarn is used in Puma garments. They put Puma T-shirts in reactors, and these T-shirts are made from 10% Seal Marine Plastic and 90% plastic collected from land”.

The type of yarn used allows for 100% recovery of the T-shirt through mechanical recycling, as mentioned in interview number 2: ”By doing this, they put everything in the reactor, and we are able to recycle it all. However, this mechanical process is only carried out when it comes to large collaborations, because it is not easy to fill a 20-tonne reactor”.

The interview reveals that Seaqual uses two distinct recycling methods. However, in order to maximise the efficiency of this mechanical recycling process, large quantities of recyclable material are required; otherwise, economic viability cannot be guaranteed.

A company similar to Seaqual is Acquafil, which specialises in the production of recycled nylon, called Econyle, through the recovery and recycling of marine waste, including fishing net residues, which are often difficult to recycle. Acquafil also uses chemical recycling and, as highlighted by interviewee 3, this has advantages: ”This process makes it possible to obtain a new nylon yarn (ECONYL®) that has the same quality and performance characteristics as nylon derived from fossil sources”.

The testimonies collected highlight the significant importance of chemical recycling in the polymer extraction process, aimed at producing new yarn.

A slightly different perspective is offered by interviewee number 5, an environmental engineer. As highlighted in the statement, Erion Packaging has been using mechanical recycling practices for years, employing only a minimal amount of chemical processes.

“We use mechanical recycling, very little chemical recycling and almost no energy recovery because we use noble polymers. We produce around 4,000 tonnes of plastic, which is nothing; we produce much more paper, which is very clean and of high quality.”

Given that the production activity of the company in question differs from that of the previous two, the recycling method adopted is different and closer to the more traditional one.

The answer to the question at hand can be found in the simplicity of the process, as well as in the know-how achieved in relation to the practice in question, as highlighted by interviewee number 5.

> *"The simplicity of the mechanical recycling process lies in the fact that it is a well-established industry, with top-level plants that have been using mechanical recycling for years. The well-established industry in Italy has led to price optimisation based on the value of raw materials."*

4.2 Environmental impacts and application of LCA

As indicated in the previous chapters, LCA is one of the most significant models for understanding the real impact of a specific material or process.

In this specific case, LCA (Life Cycle Assessment) analysis would allow us to determine the recycling method that has the least impact on the environment. During the interview, the main focus was on emissions and water consumption.

In this case, a potential improvement to be implemented concerns the logistics component.

As stated by interviewee 5:*"Our employees go directly to collect the packaging before it arrives at the recycling centres (from installers, etc.). This has significant benefits in terms of the process LCA because it means the waste has to travel less distance and the material is less damaged."*

Furthermore, interviewee 5 reiterates that it is not enough to look at only one part of the process, but rather the entire process, stating that "LCA is not just when it enters the treatment plant, but applies to the entire process, and transport has many impacts".

Acquafil's approach is more methodological, given the difficulty of recycling marine nets in particular. Their way of monitoring environmental impacts is a more scientific and integrated approach, as interviewee 4 explains:

> “With regard to the application of the LCA (Life Cycle Assessment) methodology, at Aquafil we use this tool as a strategic reference to assess the environmental impact of our processes throughout the entire product life cycle. Our activity is not limited to simply collecting waste, but includes an integrated approach that considers environmental impacts in a scientific and transparent manner, thanks in part to the constant use of LCA as a guiding tool.”

However, data is often lost during this process. As a result, LCA analysis may be inaccurate or incomplete.

This is because the waste collected often comes from developing countries that unfortunately do not yet have the necessary technology to track materials and processes.

This is evident from the interview with participant 1, who works at Seaqual:

> “An example of LCA in Seaqual: we monitor everything, but only on paper. There is still nothing digital. We are working on this, thanks in part to a collaboration with Singapore, which has a tracking programme. The others we work with do not have the technology to monitor. One of the problems is that when working with local companies, mainly in developing countries, people are not trained and therefore I am unable to track the life of the product accurately."

Every recycling process, regardless of LCA, has its own environmental impact. LCA (Life Cycle Assessment) is an analytical tool that allows this impact to be monitored.

During the interviews, it emerged that opinions vary.

Mechanical recycling is undoubtedly the most advanced approach, as it minimises consumption. Conversely, chemical recycling, as the terminology suggests, uses chemical reagents that dissolve in water. Interviewee 5 highlights the various impacts, as can be seen from his words:

> *“I consume energy and water in chemical recycling. In mechanical recycling, consumption has been reduced to a minimum thanks to experience, and is often powered by renewable energy sources (such as photovoltaic panels), resulting in zero impact.*
> *Process waste is less than 5%. Water consumption is also very low. In chemical recycling, we have the consumption of reagents, which we impact, and there is also water consumption. Energy consumption is higher than in mechanical recycling, but here too, renewable energy is used”.*

According to interviewee 5, therefore, the problems with chemical recycling are the abundant use of water and the use of reagents, which are not present in mechanical recycling. Both methods have the advantage of using renewable energy sources.

Acquafil, on the other hand, greatly emphasises the capabilities of chemical recycling, as highlighted by interviewee 3:

> "Considering the environmental and economic impacts throughout the life cycle, chemical recycling, while requiring a higher initial investment and more complex processes, offers significant benefits in terms of reducing dependence on virgin resources, decreasing emissions and promoting sustainable material circularity, contributing to a more favourable overall environmental impact in the long term".

It is undoubtedly possible to formulate two divergent opinions, although these are inevitably influenced by the type of process selected by each company for its specific use.

Participant 4 from Acquafil points out that nylon 6, the material they use, can only be recycled through chemical processes, as this guarantees higher quality recycling:"Chemically regenerated nylon 6 can be recycled virtually an infinite number of times without any loss of performance, thus promoting a genuine circular economy".

An important aspect that emerged during the interviews sparked further disagreement between the two companies operating in the same sector: Seaqual and Acquafil.

Interviewee number 2, who works at Seaqual, points out that "in terms of emissions and environmental impact, chemical pollution is worse than mechanical pollution". We would like to remind you that Seaqual has stated that it uses chemical recycling for its processes.

Nevertheless, when asked which method is best for you in the long term, respondent 2 replied that:

> *"If we compare both methods, I think it's the chemical one.*
> *Why?*

Because Seaqual Yarn is made from 10% marine plastic and 90% land-based sources of pollution. This 90% must be recycled in the correct way, and it is better to transform this 90% into yarn, which is why chemical recycling is needed."

4.3 Ecomonics factor and barriers of cost

All the elements mentioned so far are subject to a cost, which varies according to specific applications.

In addition, each process has a specific cost, which is also influenced by the technology used.

In the context of mechanical recycling, costs are generally low, thanks to advanced technology developed for this purpose. Chemical recycling technology, although developed, has not reached the level of development of mechanical recycling. This naturally implies a higher cost.

The above statement is confirmed by the statements of Seaqual and interviewee number 1, who is the head of the costs department:

"In general, it remains true that chemical recycling is more expensive—by thousands of euros.The reactors range from 8 to 24 tons.
The cost for chemical recycling is around €3,000-4,000, while for mechanical recycling it's approximately €2,000"

Despite the considerable difference in monetary value between the two options, which can amount to thousands of euros, the analysis of proportions reveals that chemical recycling is significantly more expensive than mechanical recycling.

As emerged from interview 4, Acquafil highlights the higher costs associated with chemical recycling, while confirming that, in its opinion, this process offers the greatest benefits in the long term:

" Considering the environmental and economic impacts throughout the life cycle, chemical recycling, while requiring a higher initial investment and more complex processes, offers significant benefits in terms of reducing dependence on virgin resources, decreasing emissions and promoting sustainable material circularity, contributing to a more favourable overall environmental impact in the long term".

Costs are certainly a significant factor to consider.
Take Seaqual, for example, which uses both mechanical and chemical recycling. From an economic point of view, it would be preferable for them to use mechanical recycling, as it is less expensive. However, this does not seem to be a viable option, as their main line of business is focused on the production of polymers for the creation of yarns. The use of mechanical recycling is not effective for the type of material they intend to obtain. Therefore, the use of chemical recycling is the preferred option for their specific product. Furthermore, as reported by interviewee 5, ”The best LCA method is not always the cheapest, because if I don't measure environmental externalities, then I'm not competitive”.

4.4 Quality if the product

The topic examined in this chapter is of fundamental importance for selecting the most appropriate recycling method.
The quality of the final product is of fundamental importance both in economic terms, as purchasing a poor-quality product would entail higher costs, and in terms of corporate reputation. In the recycling sector, companies that demonstrate their ability to obtain a product with identical characteristics, even though they use recycled materials, are essential for attracting an increasingly demanding clientele.
As is well known, there has been extensive discussion about chemical and mechanical recycling, although no reference has ever been made to energy recovery recycling.
During the interviews, many were unaware of this information, but interviewee 5 explained the reasons why it is often discarded: “In energy recovery, downcycling is practised, which we try to avoid more for reasons other than economic ones, because quality is lost and quality comes at a price.”

The process of ‘downcycling’ involves reducing the value of the raw material used below its initial value.

By eliminating the problem of downcycling, the primary objective of companies becomes to provide the best product to the end consumer. In this case, the chosen methodology influences the determination of the points in favour. As pointed out by interviewee number 4, the chemical recycling process guarantees a high level of material purity, eliminating most impurities:

> *"The main advantage of chemical recycling lies in its ability to completely depolymerise the material, eliminating impurities, pigments and other contaminants present in the original waste. This guarantees consistent, high quality in the final product".*

Furthermore, he points out that the chemical process is effective not only the first time, but also subsequent times. Acquafil uses nylon 6, which, when combined with chemical recycling, guarantees high quality even after multiple recycling cycles. This aspect becomes a key resource to consider in terms of costs.

In contrast, mechanical recycling does not offer these benefits. According to Acquafil, and its interviewee number 3, mechanical recycling does not allow the same levels of quality to be achieved as chemical recycling. The interview states that:

> *"On the contrary, mechanical recycling, although a valid method for some applications, does not allow the same level of purity and quality to be achieved. In this process, the waste material is simply melted down and transformed, retaining any impurities or additives that limit its reuse to a limited number of cycles (typically 2-3 times), and often involves "downgrading", i.e. a reduction in the mechanical or aesthetic properties of the recycled material compared to the original"*.

Furthermore, interviewee 3 highlights one of the main limitations of mechanical recycling: "although less energy-intensive in some phases, it may not be the optimal solution for maintaining the value of the material in the long term". As a result, the possibility of reuse is progressively reduced and the value of the material tends to decrease with each transformation cycle

In conclusion, it is important to consider the quality of recycled material, although this should not be considered secondary to other factors. As discussed above, nylon 6 has excellent characteristics that allow it to be recycled repeatedly without any loss of quality. PET is another material that stands out for its high recyclability globally. This resin is one of the most widely used in the production of polymeric materials.

As reported by interviewee 5: ”PET is a material that is 100% recyclable, with established market applications and strong market value. It is the aluminium of plastics because I can recycle it multiple times”.

4.5 Barriers to entry

Barriers to entry are often a decisive factor in choosing a recycling method. Investors and institutional bodies frequently focus excessively on economic and environmental aspects, overlooking the reality that is evident to investors and the bodies responsible for governing the sector.

This paper has considered the European situation, without dwelling on other geographical areas. However, in the interviews, the rest of the world emerges as an important factor that should not be overlooked. As is well known, the European continent is characterised by extremely strict regulations on recycling, carbon emissions and social issues.

As already highlighted in the previous chapter, the implementation of these processes involves a financial investment for companies, as quality comes at a cost.

To introduce the topic of barriers to entry, here is an illustrative example: Currently, there are numerous competitors operating in the electric car sector. These include world-renowned brands such as Tesla, BMW and Audi, which guarantee compliance with European regulations in this area. Recently, competitors from countries outside Europe, such as China and India, have begun to pose a significant threat to European car manufacturers. These countries are able to offer high-tech, high-performance vehicles at a significantly lower cost than European car manufacturers, putting their competitiveness on the global market at risk.

There may be many reasons for this, including lower quality materials or a different regulatory system that allows these companies to achieve significant savings in environmental and social compliance costs. This problem also arises in the recycling sector, where some producers are faced with strategic decisions in order to compete with non-European producers. It is certainly more effective to provide disincentives rather than incentives to people who carry out this profession in a non-compliant manner. As reported by interviewee 5:

> *"Unfortunately, if the EU wants to implement the Green Deal and the Circular Economy Act, it must introduce incentives on the one hand and economic disincentives on the other, and make itself immune to non-European markets. Today, the EU must use tariffs to combat the import of virgin recycled material that does not have the same environmental performance as that which can be managed at EU level. This is a common issue for everyone. If we want to create a European recycling industry of excellent quality, we must defend ourselves from those who offer us recycled material that may have the same technical characteristics but brings with it environmental and social externalities that are not measured. The EU is facing competition. PROTECTIONIST ECONOMIC BARRIERS ARE NEEDED".*

The message is clear: there is no intention to hinder production activities carried out abroad, but rather to stimulate growth in domestic demand, in order to automatically exclude operators who are unable to compete due to factors external to the market.

The issue under discussion was also identified in Seaquel, albeit from a different perspective. In particular, the focus is on costs and maintaining quality. Production in China, in fact, involves lower costs for both production itself and materials. As a result, product quality suffers. In order to preserve operational continuity, this issue is relevant, as highlighted by interviewee 1:

> *" Today's problem is China. Everything has a price. Products are sustainable in Europe and cost more, but there is often the problem of China, where things cost less. People know that it is impossible to compete with them if you want to maintain high standards of quality and sustainability. Fortunately, there is always someone who wants to buy Seaqual yarn, but it is also true that people would like to spend less, so there is always a bit of uncertainty".*

However, even the strictest regulations often have loopholes. As interviewee 4 from Acquafi points out:

> *" Regulatory barriers such as the absence of international standards or the lack (to date) of obligations for producers (in fact, in the aquaculture sector, there are still no clear extended producer responsibility (EPR) standards for the end-of-life management of equipment)".*

As is well known, the issue has further implications related to economic problems. Given the presence of competitors offering products at significantly lower prices, the market should try to adapt by lowering prices. However, this choice would lead to a reduction in product quality, with repercussions on all the processes involved in their creation, compromising their LCA

4.6 Future technologies and opportunities

This section will analyse new technologies that can promote innovation in recycling methods and, in addition, will evaluate ways in which their impact can be reduced. During the interviews, it became clear that transport is a significant critical issue. The transport of materials, included in the LCA, has a considerable impact on the environment. Many companies are changing the materials they use in order to reduce their environmental impact. At the same time, other companies are moving towards the use of lighter materials, such as plastic and polystyrene, due to their reduced weight, which leads to a reduction in pollution during transport and a decrease in space occupation, resulting in a reduction in the number of journeys required to transport materials to their destination. This statement is confirmed by the words of interviewee 5: " The shareholders (which include the largest manufacturers of household appliances) confirm this philosophy because there are companies that have eliminated plastic and others that still use it"

As interviewee 5 pointed out, the issue of transport is closely linked to the type of vehicles used to transport goods: "The electrification of logistics is already contributing significantly to reducing environmental impacts, and this trend is set to continue. Electric lorries are more rational than conventional vehicles. These elements have a greater impact".

Another technology that promises to be significant is artificial intelligence, which allows products to be selected for recycling in a more efficient and accurate manner. The implementation of this technology would lead to a significant improvement in the quality of input products, ensuring an optimised process and superior final quality. Below are the statements made by interviewee 5:

> *"The introduction of automated selection systems using artificial intelligence alone can improve downstream performance. Because today the problem is the input of quality materials, and without that I don't have quality output. When trained, these systems can improve the quality of selections by up to 100 times in just a few months".*

4.7 International Business Perspective

One of the objectives of this research was to analyse the results from an international trade perspective. In particular, companies such as Seaqual and Aquafil, which operate internationally and multinationally, highlight their propensity to conform to value chains that transcend national borders.

The term "global value chain" (GVC) is used in academia to describe the possibility of integrating different processes, such as production and distribution, into a global value chain. This concept is widely studied in the context of international business. The present analysis involves the relocation of part of the supply or production chain, which may be total or partial, to certain geographical areas of the world. The adoption of a business strategy can produce economic and strategic benefits, as well as offering developing countries the opportunity to improve their position in global markets. (Fazio, 2018, p. 7).

The model in question is linked to the globalisation strategies of the two companies mentioned above. Seaqual has collection facilities located almost all over the world, with a significant concentration in developing countries. Can you explain the reasons behind this choice? The main reason is the relatively low cost of labour. In addition, a phenomenon of considerable interest has occurred: the countries in question have had the opportunity to access the market and develop economically. Furthermore, from a sustainability perspective, the localisation of harvesting and processing in almost all countries allows for a reduction in transport costs and mitigates environmental impact, in accordance with current regulations.

This perspective echoes stakeholder theory, which postulates the generation of continuous benefits for stakeholders themselves.

In particular, a more accurate definition is as follows: according to Mahajan et al. (2023), stakeholder (ST) “can be defined as a theory that (i) encourages organisations to recognise and consider their stakeholders, whether they exist internally or externally to the organisation, (ii) promotes understanding and management of stakeholder needs, desires and demands, and therefore (iii) represents a holistic and responsible framework that goes beyond shareholder focus in decision-making processes, which, in turn, (iv) enables organisations to be strategic, maximise their value creation and safeguard their long-term success and sustainability”.

As mentioned above, the Seaqual initiative is a concrete example of commitment to sustainable development.

The programme targets individuals who are involved in collaborative initiatives in developing countries. This collaboration promotes long-term economic growth, fostering sustainable development.

5 Conclusion

The present study focuses on understanding the economic and environmental impact of marine waste recycling processes in the Mediterranean through the LCA methodology that companies use to monitor impacts. Furthermore, factors that may influence the choice were also taken into account in this case.

The aim of this thesis is to provide an answer to the following two research questions:

The present study aims to compare the environmental impacts of different recycling practices for polluting materials, as assessed through Life Cycle Analysis (LCA).

The factors that influence the selection of a particular method are of particular interest.

The analysis, which was conducted after collecting the testimonies of five interviewees who shared their experience in the field of recycling and sustainability, led to the conclusion that, while environmental and economic impacts are certainly very important, other factors also emerged. The type of product to be obtained influences the method to be chosen, and the same applies to the secondary raw material to be recycled. In addition to materials, costs and barriers to entry are also important factors, as they have the capacity to limit the quality and processes that will be used. Finally, as far as tracking is concerned, the type of culture under investigation will also have a significant impact.

Consequently, determining the optimal method is challenging due to the numerous influencing factors. In certain circumstances, mechanical recycling may be preferable to other methods. However, it is evident that energy recovery recycling is the least utilised method due to its detrimental impact on the quality of the final products, a factor that is unacceptable in industrial settings.

5.1 Limitation and suggestions

Furthermore, limited access to quantitative data was another limitation for this study. Certainly, quantitative analysis through interview analysis has brought to light the most salient issues; however, it is evident that quantitative support in the LCA analysis phase would have been instrumental in clarifying certain aspects.

Moreover, it is my conviction that this thesis is chiefly engineering-oriented. Consequently, I found it necessary to adapt it to my economic and managerial knowledge. A recommendation for future studies in this field is to adopt a more quantitative approach in order to facilitate more thorough analysis of individual processes and to encourage more companies to share data. For instance, one could visit factories or seek work experience within the sector.

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Appendices

Appendix 1. interview guide

Title/Research Question:
Which recycling method for marine waste (mechanical, tertiary, or quaternary) is the most sustainable according to Life Cycle Assessment (LCA), considering both environmental and economic aspects?

Date: [____]
Time: [____]
Location: [___]
Interviewer: [Gabriele Casu]
Interviewee: [____]

Introduction

This interview is part of a research project aimed at identifying which marine waste recycling method is the most sustainable based on Life Cycle Assessment (LCA). We will examine the main approaches – mechanical, tertiary, and quaternary – and evaluate their environmental and economic impacts.
The project is conducted in collaboration with [name of the institution]. The insights you share will help identify more effective solutions for sustainable marine waste management.
My name is Gabriele, I am a student, and I am interested in hearing your perspective on these topics.
All information will be kept confidential, and data collected will be anonymized. You may decline to answer any question or stop the interview at any time.
May I ask for your consent to participate in this interview and to record the conversation?

Questions

Broad Questions

1. Could you describe your experience with marine waste recycling or management?
2. Are you familiar with the LCA methodology? In what contexts have you applied or observed it?
3. Mechanical recycling: What are the advantages and challenges of this method, both from an environmental (e.g., emissions, ecosystem impact) and economic (e.g., collection, cleaning, transformation costs) point of view?
4. Tertiary recycling (chemical/thermal): Do you consider this a sustainable and scalable solution for marine waste? How do you assess its costs and potential environmental impacts?

5. Energy recovery (quaternary): How efficient is this method in terms of energy recovered relative to its environmental impact? Is it economically advantageous compared to other approaches?
6. Which method do you think has the lowest overall environmental impact, considering the full life cycle (collection, treatment, post-recycling)?
7. From a cost perspective, which method do you consider the most sustainable or convenient in the long term?
8. Some research suggests the best method in terms of LCA is not always the most economical. In your experience, how do you balance environmental impact and economic cost?
9. In your opinion, are there economic or technological barriers that hinder the adoption of the most sustainable methods?
10. Are you aware of any emerging technologies that could improve both economic efficiency and environmental impact in marine waste recycling?

Conclusion

Thank you very much for your time and for sharing your insights. Your responses will help us better understand the trade-offs between environmental and economic impacts of different recycling methods.

If you wish, I can ask a few final demographic questions (e.g., work sector, years of experience).

Thanks again for your participation. If you would like to receive a brief summary of the study's findings, I can send it to you once the analysis is completed.

For any further information or clarification, feel free to contact me at: [Gabciasu@gmail.com].

Appendix 2. Appendix title