Premi di Tesi di Laurea ENEA-CONAI 2023 e 2024
Atti delle tesi presentate

ENEA-CONAI Master Thesis Awards 2023 and 2024
Proceedings of the selected thesis

Master Thesis on Circular Economy and Sustainability

First Edition

Edited by
Erika Mancuso, Tiziana Beltrani, Laura Cutaia, Sabrina Moro Iacopini and Chiara Morbidini

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Introduzione

CONAI ha intrapreso da qualche anno un percorso di valorizzazione delle competenze e di sviluppo di progetti di formazione per i giovani, orientato alla divulgazione della conoscenza dell'economia circolare, declinata in particolare sulla filiera del packaging.

La collaborazione con il mondo accademico e con il mondo della ricerca si è rivelata pertanto imprescindibile, ai fini della messa a punto di tale strategia.

L'educazione ambientale e, ancor di più, lo sviluppo di una "cultura del riciclo", è parte integrante della mission del Consorzio, tanto che nel 2022 la sinergia con le università e gli enti di ricerca è entrata a far parte della nostra Politica Ambientale.

In questo ambito nasce la collaborazione con ENEA, l'Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Dipartimento Sostenibilità, circolarità e adattamento ai cambiamenti climatici dei Sistemi Produttivi e Territoriali, con l'intento reciproco di dare valorizzazione e diffusione al lavoro intellettuale degli studenti all'interno delle Università, che trova il suo culmine nella redazione della tesi di laurea magistrale.

Questa pubblicazione ne è la testimonianza: oltre 40 articoli scientifici che sintetizzano le migliori tesi, i migliori contributi, che hanno partecipato alla prima e alla seconda edizione del Premio CONAI per Tesi di Laurea, provenienti da tutti gli Atenei d'Italia, da Nord a Sud. Lavori di taglio diverso che prendono in esame tutti gli aspetti della circolarità – dai processi di LCA ai modelli di business adottabili dalle aziende, dall'ecodesign, alla gestione del fine vita degli scarti, ecc.

A dimostrazione che l'economia circolare è un tema di portata nazionale, discusso, dibattuto, studiato a livello di ricerca, e di forte interesse per le giovani generazioni, per il loro futuro professionale nonché personale. Il riflesso di un settore, quello del riciclo dei materiali, e ancor prima dell'industria del confezionamento e dell'imballaggio, che rappresenta un'eccellenza del *Made in Italy*.

Questa raccolta si propone di essere un osservatorio di spunti, idee e possibili soluzioni di economia circolare e sostenibilità, dando visibilità all'impegno e alla capacità creativa e di innovazione dei giovani talenti, nuovi professionisti dell'economia circolare. Nella convinzione che saranno la leva per affrontare le prossime importanti sfide che ci aspettano nel campo della sostenibilità e della salvaguardia delle risorse del Pianeta.

I contributi sono stati raccolti dalle migliori tesi inviate per la partecipazione alle due edizioni del Premio di tesi di Laurea, 2022-23 e 2023-24, e sono stati revisionati da un Comitato Tecnico Scientifico composto da ricercatori ENEA, professori, relatori delle tesi di Laurea e professionisti del CONAI. Il Comitato ha svolto l'attività di "peer review" in base alla quale ogni contributo è stato revisionato da due revisori. Gli articoli raccolti nel presente volume sono stati suddivisi in sette macroaree tematiche: *Life Cycle Assessment (LCA), End of life Management, Circular Business Models, Agri food Sector, Packaging, Sustainability and Circularity, Energy*.

Claudia Brunori, Direttrice Dipartimento Sostenibilità, Circolarità e Adattamento al Cambiamento Climatico dei Sistemi Produttivi e Territoriali, ENEA.

Simona Fontana, Direttrice Generale CONAI.

Introduction

Over recent years, CONAI has undertaken a process to enhance skills and develop training projects dedicated to young people, aimed at disseminating knowledge in the area of circular economy, focusing in particular on the packaging supply chain.

The collaboration with both academia and the research world has therefore proven to be essential for the purposes of developing this process. Environmental education and the development of a " recycling culture" is an integral part of the Consortium's mission, so much that in 2022 the synergy with universities and research institutions became part of our Environmental Policy.

In this context, the collaboration with the Department for Sustainability of ENEA, the National Agency for New Technologies, Energy and Sustainable Economic Development, was born with the mutual intent to valorize and spread the intellectual work of students within Universities, which finds its culmination in the writing of the master's thesis. This publication is the proof of this work: over 40 scientific papers that summarize the best theses, the best contributions, participating in the first and second edition of the CONAI Prize for Master thesis, coming from all the Universities of Italy, from North to South.

Different works exploring all aspects of circularity - from LCA studies to business models to be adopted by companies, from eco-design to the management of the end of life of products, etc. to finally demonstrate that the circular economy is a topic of national importance, discussed, debated, studied at research level, and of great interest for the younger generations, for their professional and personal future. In this context, the sector of materials recycling as well as the packaging and wrapping industry, which represents an excellence of Made in Italy, plays a crucial role.

This collection aims to be an observatory of ideas and possible solutions to support circular economy and sustainability, giving visibility to the commitment, creativity and innovative capacity of young talents, the new professionals of the circular economy. In the belief that they will be the lever to face the next important challenges in the field of sustainability and the protection of the planet's resources.

The contributions were collected from the best theses submitted to participate in the two editions of the Master Thesis Award, 2022-23 and 2023-24, and were reviewed by a Technical Scientific Committee composed by ENEA researchers, professors, supervisors of the theses and CONAI professionals. The Committee carried out the "peer review" activity and each contribution was reviewed by two reviewers. The papers collected in this volume were divided into seven thematic macro-areas: Life Cycle Assessment (LCA), End of life Management, Circular Business Models, Agri food Sector, Packaging, Sustainability and Circularity, Energy.

Claudia Brunori, Director of Department for Sustainability, ENEA.

Simona Fontana, General Director of CONAI.

LIFE CYCLE ASSESSMENT (LCA)

Environmental sustainability in the textile industry: analysis of the environmental footprint of the dyeing process

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Abstract

The textile industry is one of the largest consumer product industries and contributes to global economic development. At the same time, the production and consumption of textile products have a significant impact on the environment. This study thesis work, analyzes options for a circular and more sustainable textile production and consumption system. Particularly focusing on dyeing process, this work aims to present a comparison of the environmental footprint of two dyeing processes of a T-shirt: conventional industrial dyeing and organic dyeing obtained by using onion peel extract derived from the recovery of agro-food waste. The SimpaPro® software was used for the evaluation of the Life Cycle Assestment (LCA), through the analysis method ReCiPe 2016 Endpoint (E). Results show significantly lower environmental impact with organic dyeing. Future research may refine LCA analysis, consider entire product lifecycle and validate results.

Keywords: *Textile Industry; Sustainability; Circular economy; Natural Dye; Life Cycle Assessment.*

Introduction

Fast fashion culture (more clothes of lower quality and shorter production times), increasing world population, decreasing clothing prices and consumerism culture (reduction of the useful life of clothes that are considered almost disposable), these are the main factors that have led to an increase in demand and therefore in the production of clothing (or rather, overproduction) in recent years, with a consequent increase in textile waste and environmental and social impacts linked to the current linear model of production and consumption [1]. The life cycle of a textile product, such as a cotton T-shirt, requires high consumption of water and energy to process the raw material, for processing, dyeing and washing. Natural fibres, such as cotton, are produced using vast agricultural areas and large amounts of water, energy and chemicals. A lot of water is needed to produce textiles, as well as land to cultivate cotton and other fibers. For example, to produce a single cotton shirt requires 2,700 litres of fresh water [2]. Organic cotton may represent a sustainable alternative to conventional cotton, with a production system that uses less water and chemicals during cultivation and processing [3].

Dyeing is one of the most polluting production steps, consuming enormous amounts of water and releasing highly harmful chemicals into waste water that is often not properly treated before being discharged into the environment [4]. The dyes and chemicals persist, in fact, in the fabric even after washing, affecting the ecosystem and over time human health causing poisoning and serious diseases [5]. The widespread use of synthetic dyes in the textile industry has been favoured by their speed and economy in production, wide range of bright shades and better colour fastness. However, there is a renewed interest in natural dyes as better alternatives to synthetic dyes due to their eco-friendliness, ready availability, affordability, non-toxicity and sustainability [6]. This has favoured non-standardised production for certain niche textile products in which the quality of the product, the recovery of artisan and traditional processing and the link with the territory, including the use of dyeing plants to redevelop disused or degraded areas, take on a dominant character, with the advantage of contributing to the conservation of biodiversity and the sustainable and multifunctional use of resources [7, 8]. In this context mediterranean cultivations, such as the Montoro copper onion (Slow Food presidium), may represent sources of secondary raw materials for extracting dyes and recovering resources in a circular economy perspective [9, 10]. In this way, what represents the waste of one process becomes the raw material of another, strengthening a supply chain with a low environmental impact, based on reducing waste and enhancing the link between a territory and its resources.

Methods

The study evaluates the environmental impact of dyeing and using a T-shirt of 150 grams. It compares organic dyeing with vegetable dye extracted from onion peels and conventional dyeing with bifuncional reactive dye, also examining the use of dyed T-shirts in both cases. Life cycle processes included in the analysis and system boundaries are illustrated in Figure 1.

The organic dyeing considered is part of the process developed by MyraLab, an artisanal textile laboratory under development in Teggiano, Vallo di Diano, province of Salerno, financed for the start-up of non-agricultural activities in rural areas. This document provides a preliminary analysis of the environmental impact of the MyraLab process, preparing an initial assessment of its impacts that will be examined in more detail once the activity is launched. The assessment of process environmental performance was conducted using the Life Cycle Assessment (LCA) methodology. The data collected was processed using the SimaPro 9.2 calculation software.

For the organic dyeing process, two scenarios were considered:

- Scenario 1 (S1): use of water and materials (such as gallnut powder, rock alum, sodium carbonate and onion peel) for pre-etching and dyeing, with a single dyeing cycle;

- Scenario 2 (S2): re-use of 15% water and materials from scenario 1 for multiple cycles.

The consumption of water and soap for washing was considered separately and not included in the percentage calculations.

Process units for organic dyeing include: fibre preparation for dyeing or pre-etching (etching bath with tannin, etching bath with rock alum and sodium carbonate); hand washing with pH neutral soap; dyeing with onion peel extract followed by hand washing with pH-neutral soap and natural drying. For the use phase, the process unit of hand washing the T-shirt with pH-neutral soap was considered.

While for the system boundaries of the conventional dyeing process, the process unit considered is discontinuous exhaustion dyeing with reactive dye (Reactive Yellow 145 was assumed). In this case, a machine wash cycle at 40° was referred to for the use phase.

The comparison of the two processes takes into account the fact that most natural dyes fall within the mordant dyes, requiring a pre-etching step to bind the dye to the cotton fibre. Therefore, in the first process (organic dyeing), the fibre preparation step with etching baths is included. Whereas, since the reactive dye considered for conventional dyeing is not mordanted, the mordanting step is not considered in the second process. Furthermore, a standard duration of 52 washes was assumed for the use phases for a T-shirt [11], assuming no differences in colour fastness to washing.

The data used for the organic dyeing process are check-listed data provided by the MyraLab laboratory. From this data, elaborations were made to assume an industrial-scale process. Whereas the secondary data used were obtained from scientific publications in the literature and taken from the Ecoinvent 3.7.1 database. After processing, the data were entered into the SimaPro software ver. 9.2 and the ReCiPe 2016 Endpoint (E) method was used.

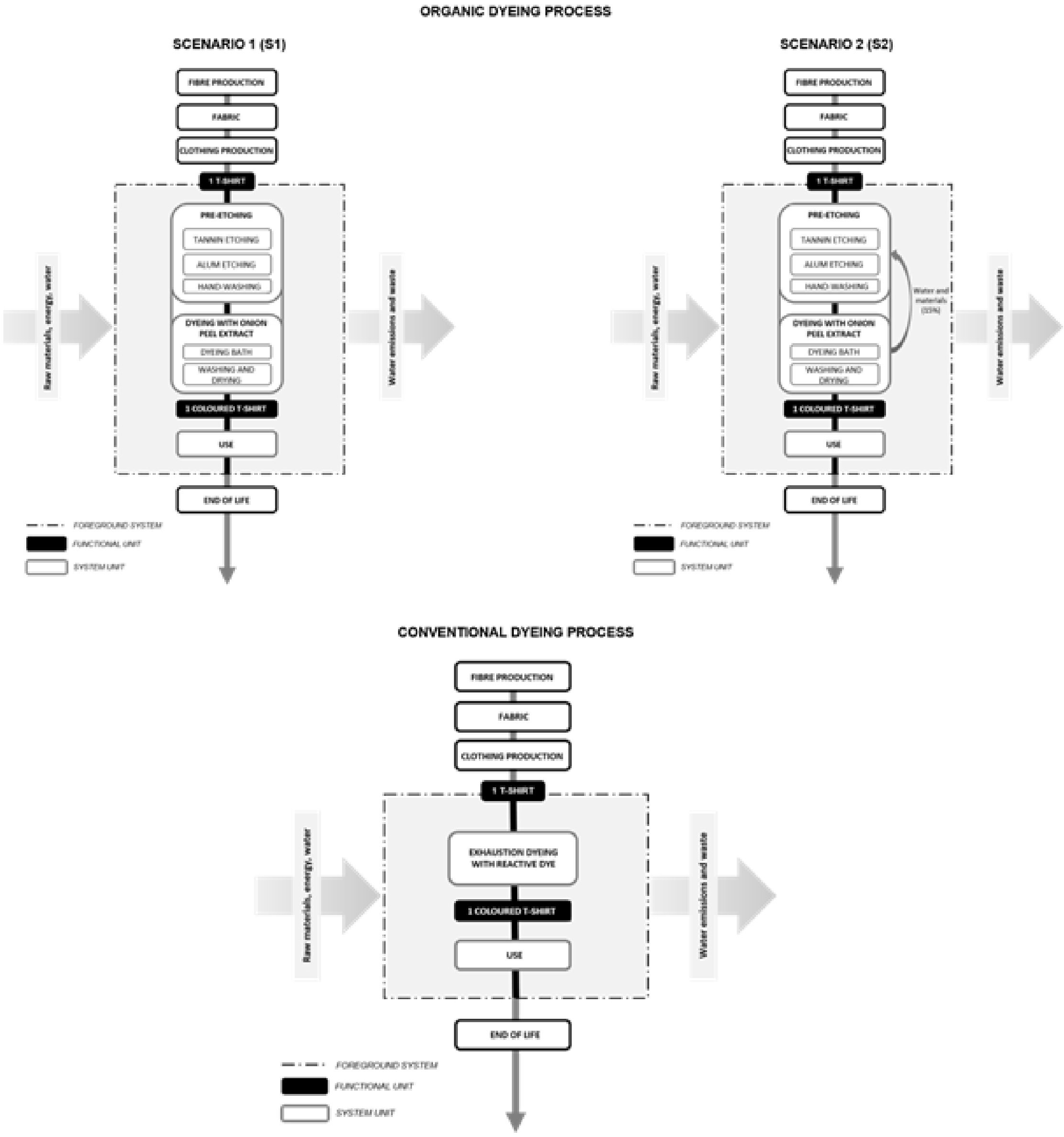

Figure 1. Life cycle flow charts and system boundaries of the dyeing processes

Findings

The midpoint assessment based on the comparison of organic dyeing (S1, S2) with conventional dyeing are illustrated in Figure 2 and shows that:

- The impact categories with the highest value are Non-Carcinogenic Human Toxicity (92.76 mPt), Carcinogenic Human Toxicity (41.05 mPt) and Global Warming, Human Health (25.67 mPt);
- The conventional dyeing process has the highest impact for Non-Carcinogenic Human Toxicity and Global Warming, Human Health categories, while the organic dyeing process (S1) has the highest impact for Carcinogenic Human Toxicity category;
- Organic dyeing (S2) has the lowest impact on all impact categories considered.

Boiler heat energy and water consumption are identified as key factors influencing the impact categories of organic dyeing (S1 and S2).

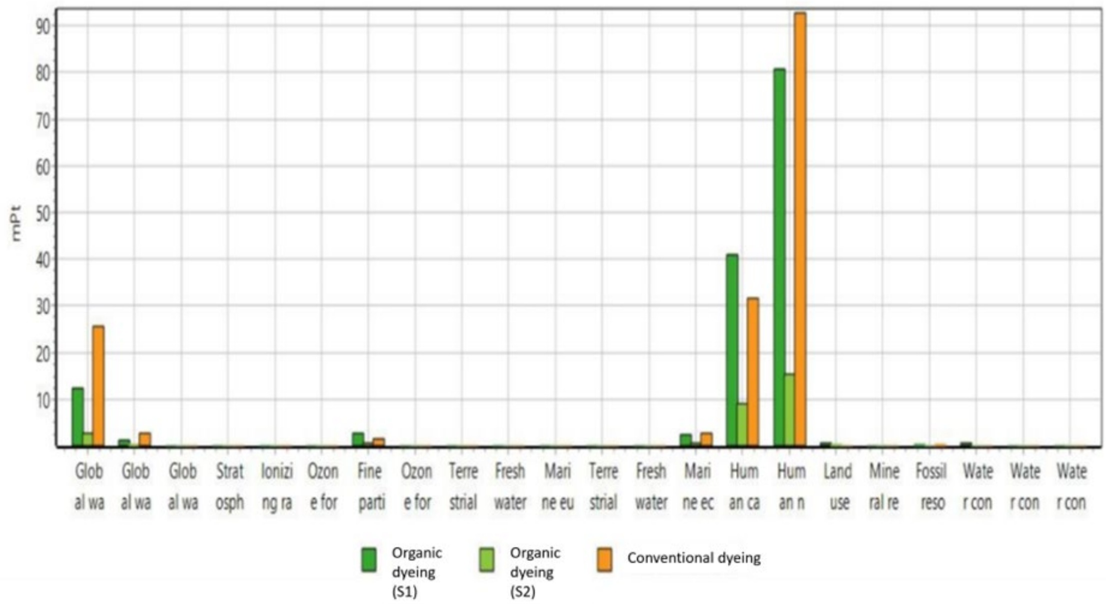

Figure 2. Comparison of organic dyeing (S1, S2) with conventional dyeing (midpoint)

When comparing organic dyeing processes (S1, S2) and conventional dyeing with organic and conventional use processes, as can be seen from Figure 3, it is observed that:

- Organic dyeing (S1), conventional dyeing and conventional use processes have higher values for each impact category than organic dyeing (S2) and organic use processes;
- The impact categories with the highest value are Non-Carcinogenic Human Toxicity (104.49 mPt), Carcinogenic Human Toxicity (54.26 mPt) and Global Warming, Human Health (25.67 mPt);
- The conventional use process has the greatest impact on the Non-Carcinogenic Human Toxicity and Carcinogenic Human Toxicity categories, while the conventional dyeing process has the highest impact on the Global Warming, Human Health category.

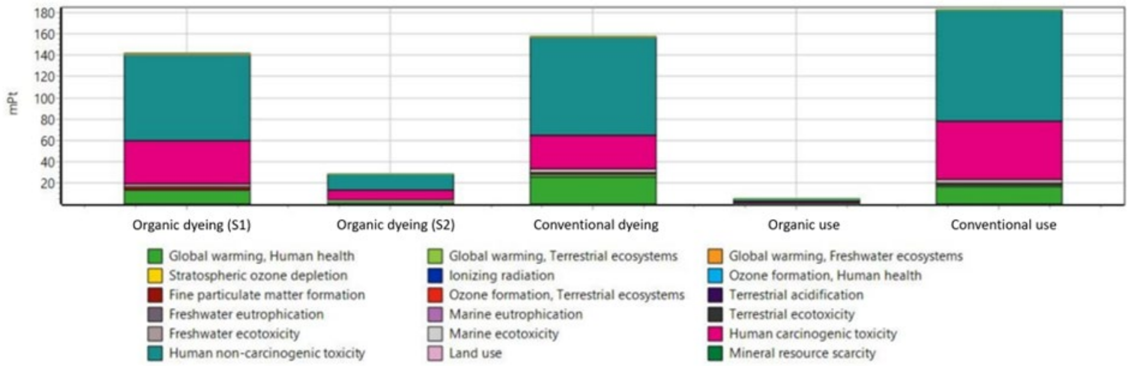

Figure 3. Comparison of dyeing processes and uses (midpoint)

Finally, in the endpoint assessment for the damage categories, as illustrated in Figure 4 it is noted that:

- The analysed processes have the greatest impact on the Human Health, Ecosystem Quality and Resource Depletion damage categories;
- The most relevant sphere is Human Health (177.12 mPt), while the impact on Ecosystem Quality (5,70 mPt) and Resource Depletion (0.40 mPt) is relatively low compared to the total detected;
- Conventional use has the greatest impact on Human Health damage category (182.63 mPt).

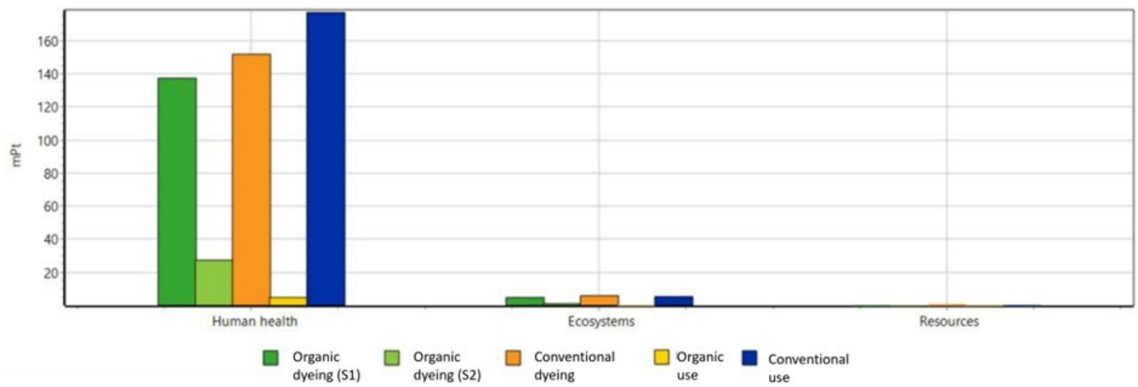

Figure 4. Comparison of dyeing processes and uses (endpoint)

Discussion/Conclusion

Textiles are fundamental to manufacturing, trade and retail, contributing to economic growth and employment globally. However, textile production and consumption patterns lead to significant environmental impacts, including waste of resources, climate change, pollution of ecosystems and use of hazardous chemicals. Much of this production is not sustainable mainly because environmental and social costs are not included in product prices. This leads to cheap clothing with high environmental impacts, often worn only a few times. A sustainable textile system should ensure safe and high-quality products at affordable prices, creating inclusive jobs with fair wages and conditions, minimising negative impacts on the environment and respecting the limits of the planet.

The LCA analysis showed that the organic dyeing process has a lower environmental footprint (-82% in scenario 1 and -10% in scenario 2) than the conventionally carried out industrial dyeing process. The impact of organic use is 97% less than conventional use. It was also observed that dyeing processes generally have a lower impact than use. Actions to be taken to improve the impact of S1 and S2 could include using a pellet boiler with lower particulate emissions as they are the main cause of the high environmental impacts observed for the category on human carcinogenic toxicity.

Possible future developments of the work carried out in this study may concern the improvement of the LCA carried out, with regard to the resolution of those aspects that make the result obtained uncertain, both due to the fact that the results will have to be validated once the organic process is fine-tuned, and due to the aspects related to the discussion of the evaluation of the lifespan of the T-shirt, which will have to be compared with the actual lifespan in terms of washing fastness of the T-shirt dyed with natural dyes. The study should then be completed by considering the entire life cycle of the T-shirt, including the pre- and post-dyeing phases (pre-treatment and finishing) in the evaluation. Therefore, any future developments will be directed at improving the above-mentioned and further aspects in order to obtain more meaningful analysis results.

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Alternative end of waste scenarios in the upholstered furniture industry: a life cycle analysis approach

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Abstract

Industrial symbiosis is becoming one of the most effective industrial tools for the transition towards a circular economy, promoting economic development while reducing the environmental impact of products and services. This study examines the potential of industrial symbiosis within the upholstered furniture district of Forlì, Italy. A comprehensive database was developed to facilitate the matching of supply and demand for waste materials, identifying expanded polyurethane as a key material for symbiotic opportunities. A Life Cycle Assessment (LCA) compared the environmental impacts of the status quo with two alternative scenarios: a centralized waste collection and chipping facility and a decentralized in-house chipping approach. Results indicate that a centralized system offers significant environmental benefits when considering the Italian electricity mix, suggesting a collective waste management strategy is advantageous for the district.

Keywords: *Industrial symbiosis; LCA; Upholstered furniture; Circular economy.*

Introduction

In the past decade, the urgency for a transition from a linear economy, characterized by a take-make-dispose model, to a circular economy has been widely acknowledged by researchers and policymakers alike [1,2,3]. The circular economy model emphasizes the recycling of materials, reduction of waste, conservation of finite energy resources, and maximization of the benefits from renewable energy sources. Among the various instruments facilitating this transition, industrial symbiosis has emerged as a critical tool [2]. As a subset of industrial ecology [3], industrial symbiosis involves the synergistic collaboration between traditionally separate industries through the physical exchange of materials, energy, water, and by-products, aiming to enhance resource efficiency and reduce waste. This practice not only offers environmental benefits by reducing resource extraction and waste but also presents economic and social advantages, such as cost savings, creation of new markets, and job opportunities [4][5].

The upholstered furniture district in Forlì, Italy, provides a significant case study for examining the potential of industrial symbiosis within the framework of the CIRCLE project (Circular Innovation and Resilient City Labs). This project, spearheaded by the

Municipality of Forlì and Romagna Tech, seeks to promote circular economy principles in the ADRION region, which includes parts of Italy, Croatia, Greece, Slovenia, and other neighbouring countries. The project's focus on developing a database to match waste supply and demand led to the identification of expanded polyurethane as a material with high potential for industrial symbiosis. This study employs a Life Cycle Assessment (LCA) to evaluate and compare the environmental impacts of the current waste management practices with two proposed scenarios aimed at optimizing the use of expanded polyurethane waste.

Methods

The methodology for this study is grounded in a comparative Life Cycle Assessment (LCA) of three distinct scenarios for managing expanded polyurethane waste generated by the upholstered furniture industry in Forlì. The scenarios evaluated are:

- Status Quo Scenario: In this scenario, expanded polyurethane waste is collected, baled, and transported to Milan, where it undergoes chipping and recycling.
- Alternative Scenario A: This scenario proposes the establishment of a centralized facility in Forlì, where collected waste is chipped and recycled locally.
- Alternative Scenario B: Each company within the industrial district installs its own chipping machine, allowing for on-site processing of expanded polyurethane waste.

Data collection

For the purpose of the research, a set of primary data have been collected through the conduction of a survey and the creation of a first sample of a database, aimed to create a comprehensive tool for matching the supply and demand of secondary raw materials among companies in the district. The following table shows the typology of the collected data. To conduct the LCA analysis, data from 9 supplying enterprises have been collected.

Table 1. Data collected

For demanding enteprises	Name	Location	NACE and ATECO codes	Activity description	Raw materials requirements
For supplying enterprises	Name	Location	NACE and ATECO codes	Activity Description	Raw material description and EWC Code

The LCA methodology

The LCA methodology ecompasses the following phases:

- Goal and Scope Definition: The primary objective is to assess the environmental impact of managing polyurethane waste and to provide stakeholders with data to support decision-making in waste management practices. The system boundaries include only the stages related to recycling processes and waste management, specifically focusing on the production of chipboard from expanded polyurethane.
- Life Cycle Inventory (LCI): Data collection and quantification of inputs and outputs related to energy, raw materials, and emissions for each scenario. The inventory considers primary data sources and the European Life Cycle Database (ELCD) 3.2.
- Life Cycle Impact Assessment (LCIA): Using the ReCiPe 2016 Endpoint (H/A) method, the LCA evaluates multiple impact categories, including global warming potential, ozone depletion, particulate matter formation, and resource scarcity, under both the Italian electricity mix and a 100% photovoltaic (PV) scenario.
- Interpretation: The results are analyzed to identify the scenario with the least environmental impact and to provide recommendations for stakeholders in the upholstered furniture district.

Findings

The LCA results for the three scenarios are summarized below, highlighting the environmental impacts across various categories:

- Status Quo Scenario: This scenario exhibited the highest environmental impact across most categories, primarily due to the long-distance transport of waste to Milan. The transport process significantly contributed to global warming potential, ozone depletion, and fossil resource scarcity.
- Alternative Scenario A: Establishing a centralized facility in Forlì for chipping and recycling polyurethane waste demonstrated a substantial reduction in environmental impact compared to the status quo. The proximity of the facility minimized transport emissions, and the centralized processing was more efficient in terms of energy consumption and resource use.
- Alternative Scenario B: Although this scenario had the lowest overall environmental impact due to the elimination of transport, the practicality of implementing in-house chipping machines for all companies was limited. The high initial investment costs, space requirements, and potential inefficiencies for small companies made this scenario less feasible despite its environmental benefits.

Table 2. Environmental impact assesment results for the 3 different scenarios: *Status quo*, *Alternative scenario A*, and *Alternative scenario B.* The assessment covers multiple impact categories, each representing different environmental effects such as global warming, ozone depletion, ionizing radiation, and various forms of ecotoxicity and human health risks

Impact category	*Status quo*	*Alternative scenario A*	*Alternative scenario B*
Global warming	8,58E-02	4,80E-02	4,72E-02
Stratospheric ozone depletion	3,50E-08	6,35E-09	5,82E-09
Ionizing radiation	6,90E-04	3,57E-04	3,51E-04
Ozone formation, Human health	3,38E-05	1,86E-06	1,29E-06
Fine particulate matter formation	4,92E-05	2,55E-05	2,50E-05
Ozone formation, Terrestrial ecosystems	3,46E-05	2,65E-06	2,08E-06
Terrestrial acidification	1,32E-04	8,10E-05	7,99E-05
Freshwater eutrophication	4,83E-06	8,66E-08	2,25E-09
Marine eutrophication	1,07E-07	7,56E-08	7,48E-08
Terrestrial ecotoxicity	8,10E-01	1,94E-02	5,30E-03
Freshwater ecotoxicity	1,36E-04	3,90E-06	1,54E-06
Marine ecotoxicity	5,97E-04	1,70E-05	6,69E-06
Human carcinogenic toxicity	4,34E-05	1,06E-05	9,99E-06
Human non-carcinogenic toxicity	1,19E-02	4,19E-04	2,14E-04
Land use	5,42E-05	2,88E-05	2,83E-05
Mineral resource scarcity	3,75E-06	1,02E-06	9,70E-07
Fossil resource scarcity	1,27E-02	2,22E-04	4,35E-07
Water consumption	3,71E-04	3,70E-04	3,69E-04

The Break-Even Point (BEP) analysis indicated that with only two companies participating in a centralized system, Alternative Scenario A became more environmentally advantageous than Alternative Scenario B when using the Italian electricity mix. Under a 100% PV scenario, the number of companies required to achieve a BEP increased significantly, emphasizing the importance of electricity source in the overall assessment.

Discussion/Conclusion

The principles inferred from this study underline the significance of implementing a more efficient waste management as an effective strategy for advancing circular economy practices within the upholstered furniture industry, aiming at better valorise production residuals through recycle. The analysis demonstrates that centralized waste management, specifically Alternative Scenario A, offers substantial environmental benefits by minimizing transport emissions and optimizing resource use.

However, several limitations and challenges were identified. The decentralized approach (Alternative Scenario B), while environmentally superior, presents practical difficulties for smaller enterprises due to high initial costs and space constraints for chipping equipment. Additionally, the dependency on electricity source significantly influences the environmental outcomes, highlighting the need for integrating renewable energy solutions to maximize sustainability.

The theoretical implications of this work suggest that a centralized waste management can significantly contribute to reducing the environmental footprint of industrial sectors, promoting resource conservation, and enhancing economic resilience. Practically, the findings advocate for the establishment of shared facilities to streamline waste management processes, thereby supporting small and medium-sized enterprises (SMEs) in participating in circular economy initiatives without substantial financial burdens.

In conclusion, the study recommends the implementation of a centralized waste management system for the upholstered furniture district in Forlì. This approach provides a balanced solution, leveraging collective resources and infrastructure to achieve significant environmental and economic benefits. Future recommendations include:

- Enhancing Collaboration: Foster partnerships among companies to facilitate the exchange of materials and by-products, supported by a robust database system.
- Financial Incentives: Develop financial mechanisms and incentives to support the initial setup of centralized facilities and encourage the adoption of industrial symbiosis practices.
- Regulatory Support: Streamline regulatory frameworks to facilitate easier approval and compliance for waste reuse projects, thereby reducing barriers to industrial symbiosis.
- Renewable Energy Integration: Promote the use of renewable energy sources within the industrial district to further enhance the sustainability of waste management practices.
- Ongoing Research and Development: Encourage continuous research to explore innovative recycling technologies and methods to improve the efficiency and effectiveness of industrial symbiosis systems.

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Quantification of the environmental benefits associated with the activity of the “PANTA REI” reuse centre with the LCA metodology

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Abstract

The research proposes a Life Cycle Assessment-based methodology for the evaluation of the environmental impacts associated with the activity of a reuse centre. The net environmental impact of used goods is obtained by composing two contributions of the system: the “avoided” impacts of the first life (production, transport, use, end-of-life), and the “additional” impacts of the second life (transport, reuse). To compare new goods with used ones, specific parameters affecting the system are defined: susbstitution rate, quality rate, and energy performance rate. The methodology is applied to the “Panta Rei” reuse centre in Italy. The analysed reuse centre yielded environmental benefits in 6 out of 16 impact categories according to EF 3.0 characterization method. Outcomes would change with different values of the rates: e.g. 100% substitution of new with used goods would bring benefits across all 16 categories. The research highlights consumers’ role in ensuring benefits of waste prevention activities.

Keywords: *Reuse centre; Circular economy; Life Cycle Assessment; Waste prevention; Consumers’role.*

Introduction

The current dominant economic model operates on a linear basis, assuming unlimited resources and following a "take-make-dispose" paradigm. This results in a constant demand for raw materials and significant waste generation. To address these issues, the transition to a circular economy is essential, aiming to decouple economic growth from resource depletion and environmental harm. The "Waste Framework Directive" (Directive 2008/98/EC) [1] establishes a legal framework for waste management in Europe, prioritizing prevention and reuse, followed by recycling, other recovery processes, and disposal. The present research seeks to define a methodology to examine whether and to what extent the reuse of goods can actually bring environmental benefits. The evaluation is performed through the development of a Life Cycle Assesment (LCA)-based ad-hoc model. To test its effectiveness, the model has been applied to a case study, i.e. the “Panta Rei” reuse centre in Italy (Vimercate, MB), a structure dedicated to the collection and the subsequent sale of reusable used goods.

Methods

A reuse centre markets a variety of used goods within N different product categories. For quantifying the net environmental impact of a product within each A-th product category ($I_{A,prod}$), the proposed LCA-based model considers that the system comprises two parts: the first life of the good (production, packaging, transport from industry to the first user's home, use, collection and transport of waste to the final treatment plant, end-of-life) and the second life of the good (transport from the first user's home to the reuse centre, transport from the reuse centre to the second user's home, reuse). The impacts allocated to the first life constitute avoided environmental impacts thanks to the reuse activity ($I_{A,av}$, negative in sign), while those related to the second life are considered as additional environmental impacts ($I_{A,add}$, positive in sign) (Equation 1).

$$I_{A,\,prod} = I_{A,add} + I_{A,av} \times r_{A,s} \times r_{A,q} \quad \text{(Equation 1)}$$

Three parameters, whose domain of existence is [0;1], are integrated in the model:

- $r_{A,s}$: it is the substitution rate of the products within the A-th product category. A value of 0 means that the purchase of the used good is not necessary, i.e. it is additional and not substitutive, representing the situation in which the user is just attracted by the cheap price of a used good, but does not really need it. A value equal to 1 means, instead, that the purchase is necessary: if the user did not purchase the used good, he would purchase it new elsewhere. This rate value, which takes into account the rebound effect, can be calculated by collecting data directly from reuse centers users, as the ratio between the number of affirmative answers to the question "Does the used product you are buying replace the purchase of a new one?" for goods of the A-th category, and the total number of answers (affirmative and negative) to that question for the same A-th category;
- $r_{A,q}$: it is the quality rate of the products within the A-th product category. It reflects the quality of the used good in terms of expected average lifespan: it is the ratio between the expected average lifespan of a used good and the expected average lifespan of a new one;
- in the case of electrical and electronic equipment, a further coefficient is introduced: it is the energy performance rate of the products within the A-th product category, r_{A,e_p}. It distinguishes the use phases of a new good and a used one: it is the ratio between the specific energy consumption of the new good and the specific energy consumption of the used good.

Consequently, the combination of the two parts of the system yields the quantification of the net environmental impact generated by the reuse of one unit of product. If the resulting net environmental impact is negative in sign (i.e. the absolute value of the avoided impact is higher than the additional one), it means that the reuse practice brings an environmental benefit. Conversely, if the resulting net environmental impact is positive in sign (i.e. the absolute value of the additional impact is higher than the avoided one), it means that the reuse practice causes an environmental burden. Then, by integrating the information on the average mass of used products within the A-th product category sold in a timeframe, and the number of products within the A-th product category sold in that timeframe, the net environmental impact associated with each A-th product category is determined. By summing up the contributions from the N product categories, the total net environmental impact associated with the entire activity of the reuse centre in that timeframe is ultimately obtained.

In order to explore the effects of the assumptions made for some key parameters (including not only the newly introduced rates, but also other parameters, as discussed in existing literature, such as the transportation distance of used goods, and the product utilisation time) on the final results of the analysis, conducting sensitivity analyses is recommended: data are changed to assess how the results change accordingly. Breakeven analyses are also recommended to determine the minimum value of parameters in correspondence of and above which the net environmental impact associated with each product shifts from a positive in sign value to a negative in sign value.

Findings

In order to evaluate the effectiveness of the proposed model, it has been applied to a case study, the Panta Rei reuse centre in Vimercate (MB, Italy), in reference to one year of sales of used goods, i.e. year 2022. Due to the variability of products involved in the activity, ten significant product categories were selected through a preliminary assessment [2]. In turn, due to the variety of product types included in each product category, a specific product for each product category itself was selected for the modeling as representative of the category: a T-shirt, a glass, a book, a television, a computer, a bicycle, a bed, a pair of shoes, a baby carriage, and a hairdryer [3].

In order to quantify the net environmental impact generated by reusing each product chosen for the ten significant product categories sold by the Panta Rei reuse centre, ten LCA analyses are implemented in parallel, according to the LCA framework [4, 5], and applying the proposed model (Equation 1). The substitution rate values for the ten analysed product categories were obtained through a survey submitted to 577 users of the Panta Rei reuse centre in April 2023 [2]. As for the quality and the energy performance rates, due to the difficulty in defining a precise value, in the base scenario (i.e. the reference modelling) they are assumed equal to 1 for all the analysed products, i.e. there is equivalence between a new good and a used one in terms of both expected average lifespan and energy consumption. Subsequently, in order to understand how the variation of the values assumed for some parameters affects the final results of the analysis, some sensitivity analyses are performed (Figure 1). Furthermore, some breakeven analyses are conducted for the substitution, quality, and energy performance rates. For the environmental impact assessment, the 16 impact categories proposed by the Environmental Footprint method (EF 3.0), recommended by the European Commission [6], are examined.

The results related to the base scenario (Figure 1) showed that the activity of the whole Panta Rei reuse centre in 2022 has allowed for environmental benefits in only 6 out of 16 impact categories: ecotoxicity, freshwater; eutrophication, freshwater; eutrophication, marine; human toxicity, non-cancer; resource use, minerals and metals; water use. The sensitivity analyses applied to the case study highlighted important variations in the results. Setting the substitution rate equal to 1 for all the product categories, the activity of the reuse centre would bring environmental benefits in all 16 impact categories. In case of 75% decrease in the distance between the reuse centre and the second user's home, environmental benefits would occur in 10 out of 16 impact categories: acidification; ecotoxicity, freshwater eutrophication, freshwater; eutrophication, marine; eutrophication, terrestrial; human toxicity, cancer; human toxicity, non-cancer; particulate matter; resource use, minerals and metals; water use. For a substitution rate equal to 1 for all product categories, in addition to the aforementioned decrease in distance, environmental benefits would occur in all 16 impact categories. In case of a joint decrease in the values of the quality and energy performance rates, equal to 0.5 and 0.8 respectively, keeping the actual substitution rates, i.e. considering the worst situation for the valorisation of the reuse centre, environmental benefits would occur in only 2 out of 16 impact categories (resource use, minerals and metals; water use). Further considering a substitution rate equal to 1 for all product categories, environmental benefits would be obtained in all 16 impact categories.

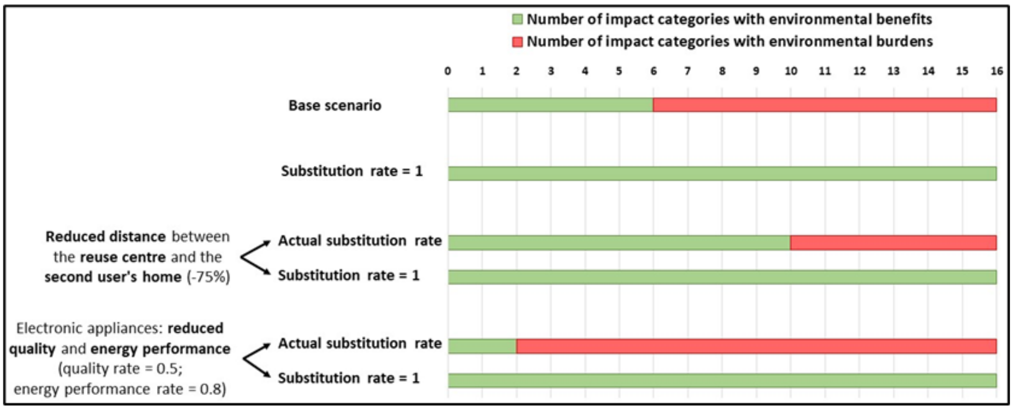

Figure 1. Results of applying the proposed model to the Panta Rei reuse centre

Table 1 presents the results of the breakeven analysis on the substitution rate (for breakeven analyses on other rates, refer to Nichilo (2023) [3]). Results showed that, for some products (in red, e.g. glass), even for the highest substitution rate, there is no environmental benefit in even 50% of the impact categories. For other products (in orange and yellow, e.g. T-shirt), environmental benefits are observed only at high substitution rates.

For others (in light green, e.g. baby carriage), environmental benefits are evident even at relatively low substitution rates. Finally, the substitution rate has a negligible effect on the sign of the total net impact of the product "bed" (in dark green). In this last case, the net impact is almost always negative, even for substitution rates below 1%: this occurs because the impacts associated with the first life of the good (avoided impacts), such as production, are significantly higher than the impacts associated with its second life (additional impacts, mainly related to transportation).

Table 1. Results of the breakeven analysis on the substitution rate for the Panta Rei reuse centre

% of impact categories with environmental benefit	T-shirt	Glass	Book	Television	Computer	Bicycle	Bed	Shoes	Baby carriage	Hairdryer
100%	0.95	\	\	0.34	0.55	0.69	<1%	0.99	0.26	\
75%	0.50	\	\	0.19	0.43	0.37	<1%	0.74	0.08	0.77
50%	0.30	\	\	0.12	0.30	0.30	<1%	0.53	0.06	0.58

Discussion/Conclusion

Reuse, defined by Directive 2008/98/EC as "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived", is among the prevention measures in the waste management framework, and is crucial for the transition from the linear to a circular economy. In this framework, the focus of the study was to define an LCA-based ad-hoc model for the environmental assessment of the reuse practice, introducing a group of specific parameters functional to carry out accurate analyses. The proposed model was then applied to a case study, i.e. the Panta Rei reuse centre in Italy, to examine its effectiveness. It emerged that the environmental benefit associated with the reuse of a single good, and consequently with the entire activity of a reuse centre, depends on various factors, the most significant of which is the substitution rate. The introduction of this rate and its evident impact on the results underscores not only the importance of conscious purchases, but also how its integration in LCA analyses leads to a more accurate assessment of the potential benefits. Therefore, in promoting reuse practices, it is crucial to accompany these efforts with advice about avoiding running into rebound effects, and to monitor consumer behaviour in order to measure actual, rather than merely hypothetical, benefits. The research underlines the key role of consumers in ensuring that a waste prevention activity actually brings true environmental benefits. In conclusion, three key actions have been identified to improve the environmental performance of the reuse practice promoted by reuse centers: raising citizens' awareness of the impacts of their actions, promoting sustainable mobility when going back and forth to purchase a used good, and reducing distances between reuse centers and consumers. It would be beneficial to discuss the practical feasibility of these aspects with the managers of the reuse centres: this could both provide strategic insights, and help to identify and integrate any other issues not covered by the study. From a methodological perspective, some aspects need to be considered, such as the potential difficulty in collecting consistent rate values for the sold goods, and the possible limitations arising from modelling a limited number of products, which may not adequately capture the high variability of goods sold by reuse centers. Moreover, it is advisable to improve the proposed model by integrating other important factors, such as the number of reuses of the same used good (the current model assumes a single reuse, which is reasonable for some products like electrical appliances, but not for others like books), and the potential socioeconomic impacts associated with the practice of reuse. In fact the current model focuses on the sole environmental impacts, while reuse centers also play a significant socioeconomic role by providing affordable goods, and engaging in activities like workshops, employment opportunities, and community awareness initiatives.

Acknowledgement

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Environmental impact assessment of aggregates. A case study in UP2YOU: upcycling in the circular economy context

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Abstract

The depletion of natural resources has necessitated the development of sustainable alternatives, promoting a transition towards a circular economy. This study compares the environmental impacts of quarry-extracted silica sand with urban waste glass sand to identify the more environmentally sustainable option. The Life cycle assessment (LCA) methodology was used to evaluate both materials. Results indicate that post-consumer glass recycling, despite transport distance impacts, provides significant environmental benefits by reducing the need for virgin materials and diverting waste from landfills.

Keywords: *Circular economy; Life Cycle Assessment; Glass recycling; Environmental impact; sustainability.*

Introduction

The depletion of natural resources and the increasing generation of waste have led to a growing focus on sustainable solutions such as the circular economy. In this context, recycling materials like glass presents an opportunity to reduce the demand for virgin raw materials and minimize the environmental impact associated with extraction processes. This study presents a comparative analysis between quarry-extracted silica sand and recycled glass sand from urban waste, aiming to identify the product with the best environmental performance.

Using the Life cycle assessment methodology in accordance with ISO 14040:2006/Amd 1:2020 Environmental management — Life cycle assessment — Principles and framework Amendment 1 standards and ISO 14044:2006Environmental management — Life cycle assessment — Requirements and guidelines, the environmental impacts of the two products were evaluated throughout their life cycles. The objective is to provide objective data to support the optimization of industrial processes and the reduction of overall environmental impact. The choice of recycled glass sand as an alternative is driven by the need to promote industrial symbiosis practices and the potential use of materials that would otherwise be destined for landfills.

Methods

The LCA is the standardized technical approach for identifying and quantifying the overall environmental burdens of a product, process, or service throughout its entire life cycle, from cradle to grave (Figure 1) (Figure 2). This methodology encompasses all stages of the life cycle, including sourcing raw materials, production processes, transportation, use, and end-of-life. The primary goal of this study is to evaluate and compare the environmental impacts of quarry-extracted silica sand and urban waste glass sand, identifying opportunities to minimize these impacts. The LCA conducted in this thesis follows a rigorous methodological protocol defined by the ISO 14040:2006/Amd 1:2020 Environmental management — Life cycle assessment — Principles and framework Amendment 1 standards and ISO 14044:2006Environmental management — Life cycle assessment — Requirements and guidelines, ensuring a comprehensive evaluation of the environmental burdens associated with the two materials. The phases of the LCA are as follows:

- Goal and Scope Definition

This phase involves setting the goals of the study, defining the functional units, and establishing the system boundaries. For this study, the objective is to compare the environmental impacts of quarry-extracted silica sand and urban waste glass sand up to the gate of the company.

To provide a clear understanding of the processes involved, the production flows for both materials are illustrated in:

- Figure 1 depicts the production process of quarry-extracted silica sand, beginning with mining and extraction. The material undergoes a wet technology cycle involving washing and sorting, followed by a dry technology cycle for further refinement. Electrical energy and heat are used throughout, with the final product transported to the glass industry.

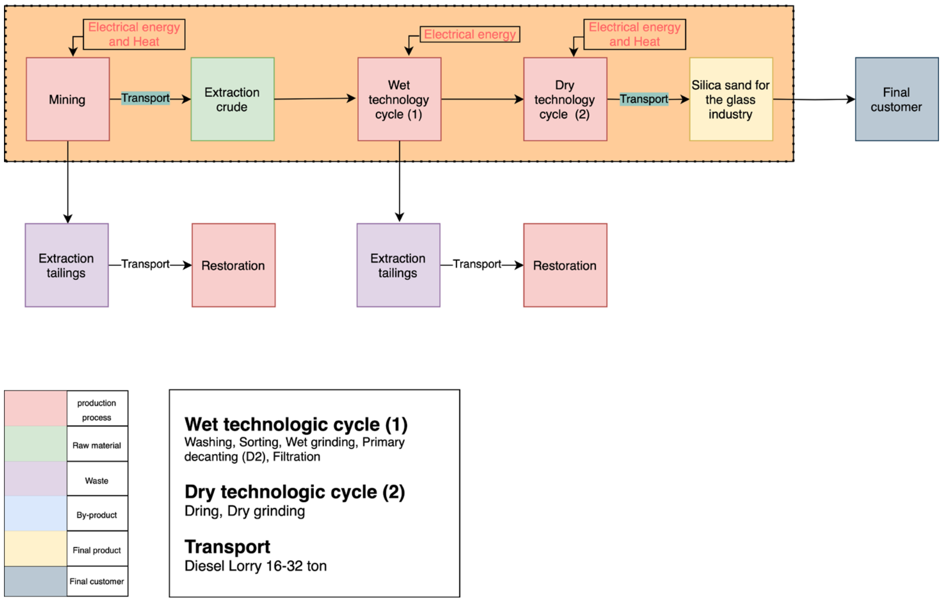

Figure 1. Silica sand flowchart

– Figure 2 illustrates the process for recycled glass sand. Post-consumer glass is collected, sorted, and crushed into homogeneous pieces. The glass cullet is then processed through wet and dry cycles, similar to silica sand, but includes the recovery of by-products and avoids landfill disposal. The end product is supplied to the glass industry, demonstrating a circular approach by reusing waste materials.

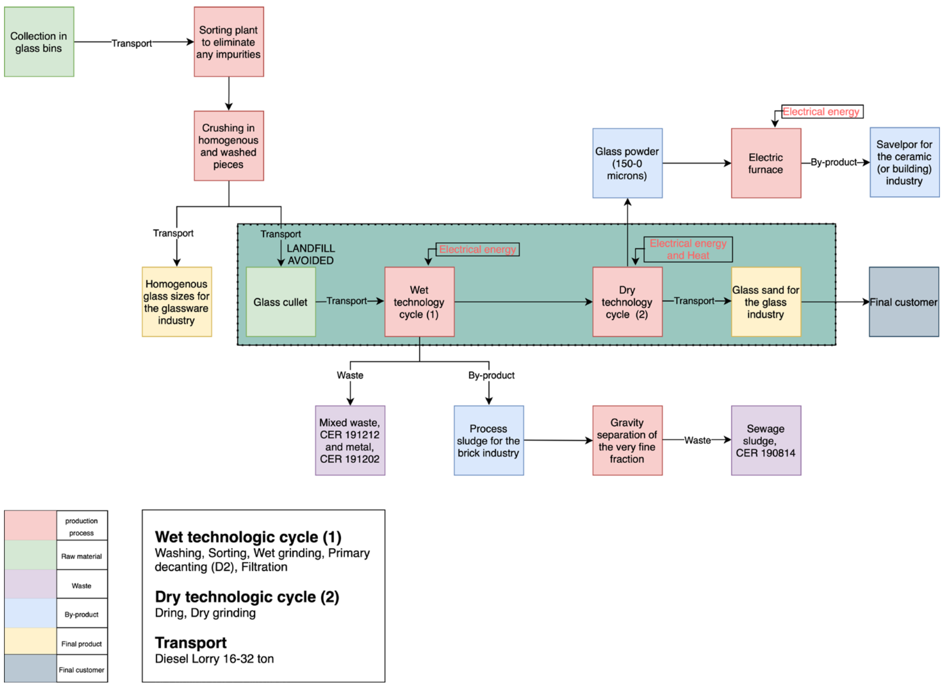

Figure 2. Glass sand flowchart

- Life Cycle Inventory (LCI)

In this phase, detailed data collection and quantification of inputs and outputs for the product systems being studied are performed. The data collected includes information on raw material extraction, processing, transportation, and end-of-life stages for both silica sand and glass sand. The Life Cycle Inventory (LCI) aims to provide a comprehensive account of all energy and material flows, as well as emissions to the environment, involved in the production and use of the materials.

- Impact Assessment

The impact assessment phase evaluates the potential environmental impacts associated with the inputs and outputs identified in the inventory analysis. The study considers impact categories such as global warming potential (GWP), energy consumption, water use, and pollution levels. This phase quantifies the environmental burdens in terms of these categories, providing a clear and detailed comparison between silica sand and glass sand.

- Interpretation of Results

The final phase involves interpreting the results of the impact assessment, drawing conclusions, and identifying areas for improvement. This interpretation includes a comparison analysis to identify critical points in the raw material choice where environmental improvements can be made. The point is to provide actionable insights for reducing the environmental impacts of the materials studied.

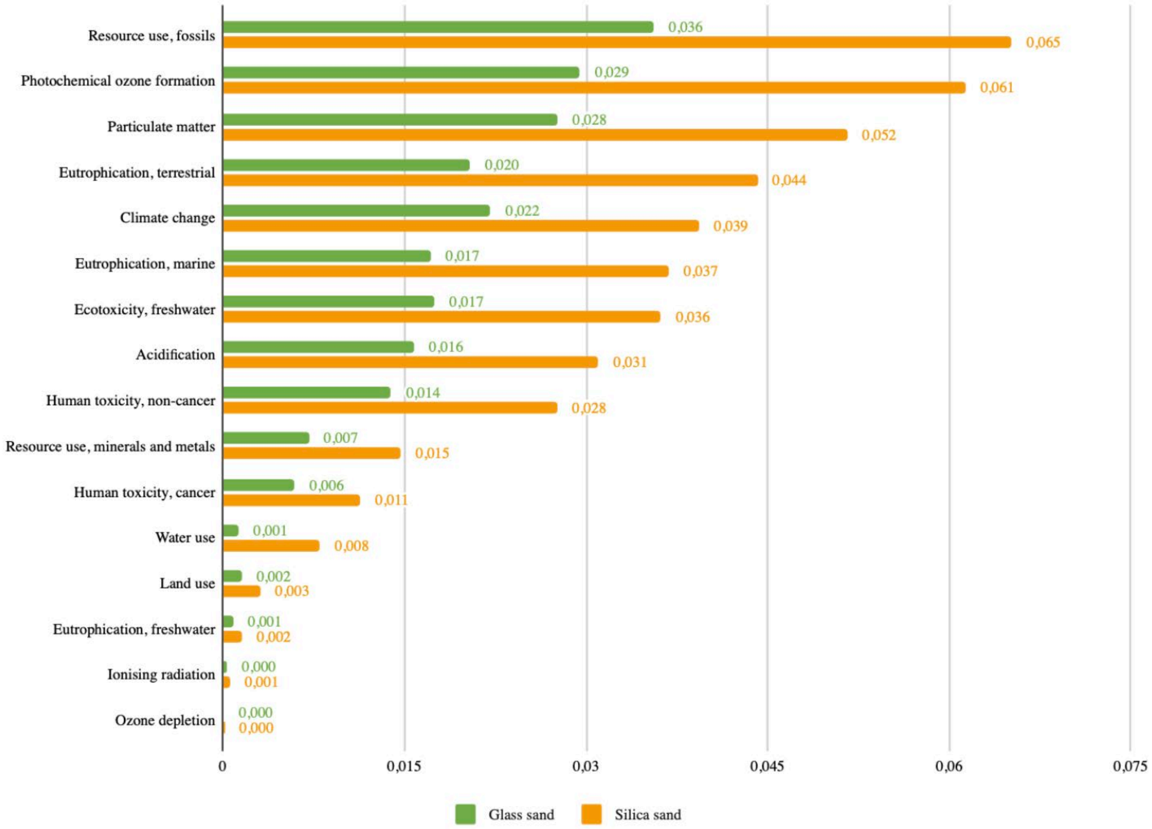

Figure 3. Comparison among impacts produced from different raw materials

Results and discussion

The Life Cycle Assessment (LCA) conducted in this study reveals significant differences in the environmental impacts of quarry-extracted silica sand and urban waste glass sand. The findings indicate that glass sand offers several environmental advantages over silica sand across multiple impact categories [5].

Firstly, the global warming potential (GWP) is markedly lower for glass sand compared to silica sand. The glass sand production process results in 167 kg CO_2 eq, whereas silica sand production results in 297 kg CO_2 eq. This 43.8% reduction in GWP can be attributed to the avoided emissions associated with the extraction and processing of virgin materials. The recycling of post-consumer glass significantly curtails these emissions, leading to a lower overall carbon footprint.

In terms of energy consumption, glass sand again demonstrates superior performance. The total energy required for producing glass sand is 2310 MJ, compared to 4230 MJ for silica sand, reflecting a 45.4% reduction. This substantial energy saving is due to the less energy-intensive nature of the glass recycling process compared to the extraction and processing of silica sand.

Water use is another critical area where glass sand outperforms silica sand. The production of glass sand requires 14.6 m³ of water, significantly lower than the 91.8 m³ needed for silica sand production. This represents an impressive 84.1% decrease in water consumption, emphasizing the efficiency of the glass recycling process in conserving water resources.

Additionally, the use of fossil resources is considerably lower for glass sand, with a reduction of 45.4%. The fossil resource consumption for glass sand is 2310 MJ, while for silica sand it is 4230 MJ. This difference is driven by the energy savings associated with recycling processes and the reduced need for virgin material extraction.

The study also highlights the environmental benefits of waste management. By diverting substantial amounts of post-consumer glass from landfills, the recycling process mitigates the environmental burden associated with waste disposal. This diversion aligns with the principles of the circular economy, promoting resource recovery and minimizing waste.

Transport logistics play a significant role in the overall environmental impact. The study finds that using rail transport for glass sand, as opposed to road transport, offers notable environmental advantages. Rail transport reduces greenhouse gas emissions and energy consumption, further enhancing the sustainability profile of glass sand.

These findings underscore the environmental advantages of using recycled materials and optimizing transport logistics to achieve environmental sustainability [5]. Glass sand not only provides a lower environmental impact across multiple categories but also supports sustainable waste management practices and the principles of the circular economy.

The conclusions drawn from this study highlight several key principles and generalizations based on the results:

1. **Environmental Performance**: Glass sand demonstrates superior environmental performance compared to silica sand, with significant reductions in global warming potential, water use, and fossil resource use. This indicates that recycled materials can effectively lower environmental impacts [6].
2. **Waste Management and Circular Economy**: The process of recycling post-consumer glass into glass sand not only conserves natural resources but also effectively diverts waste from landfills. This aligns with the principles of the circular economy, promoting resource recovery and minimizing waste [7].
3. **Transport Logistics**: The study highlights the importance of transport logistics in the overall environmental impact. Rail transport for glass sand offers substantial environmental benefits over road transport, reducing greenhouse gas emissions and energy consumption.
4. **Theoretical and Practical Implications**: The findings support the theoretical framework of the circular economy and provide practical implications for industries looking to adopt sustainable materials. The results advocate for

increased use of recycled materials and optimization of transport logistics to enhance environmental sustainability.

5. **Exceptions, Problems, and Limitations**: The study acknowledges certain limitations, such as the potential variability in data quality and the specific context of the analyzed company, which may not be universally applicable. Additionally, the study highlights the need for further research into the long-term sustainability and economic feasibility of using recycled glass sand on a larger scale.

Conclusion and recommendations

- Promote the use of recycled glass sand in various industrial applications to reduce environmental impacts.
- Optimize transport logistics by prioritizing rail transport over road transport to further enhance sustainability.
- Encourage further research into improving the recycling processes and expanding the use of recycled materials.
- Support policies and initiatives that foster the adoption of circular economy practices and the use of sustainable materials.

These conclusions and recommendations aim to guide industries and policymakers in making informed decisions that contribute to environmental sustainability and resource conservation [8].

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END OF LIFE MANAGEMENT

Implementing circular economy evaluation of implications related to an innovative waste to resource management scenario

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Abstract

Circular Economy (CE) has the potential to enhance eco-performance and contribute to sustainable development by recovering and valorizing waste and residues. However, a comprehensive methodology to measure CE transition and progress is lacking. This study investigates the implications of CE implementation in the industry, focusing on Spent Bleaching Earth (SBE) residue valorization in brick manufacturing. Life Cycle Assessment (LCA), Circular Indicators, and Economic Advantage compare a CE-oriented strategy with a business-as-usual approach for SBE management. Results suggest that while the environmental benefits of the CE approach may not be immediately clear, it offers significant economic benefits, with annual savings in the thousands of euros. Resource scarcity is also positively influenced, with a 20% reduction in total waste generated. The research Degree Thesis suggests that integrating SBE repurposing in the ceramic industry offers a viable avenue for advancing CE within industrial contexts, providing insights into potential methodologies for implementation.

Keywords: *Circular economy; CE implementation; Life Cycle Assessment; Spent Bleaching Earth; Resource Valorization.*

Introduction

With global population growth and industrial expansion putting increasing pressure on natural resources and ecosystems, the prevailing linear production model, characterized by the 'take-make-use-dispose' approach, has proven to be problematic in terms of economic, social, and environmental sustainability [1]. In Europe, industries account for over 20% of CO_2 emissions, high water and energy demand, and generate more than half of the continent’s waste. Globally, only 8.6% of the resources annually fed into the economy are recycled back into society [2]. The Circular Economy (CE) emerges as a promising solution to mitigate waste generation, enhance resource efficiency, and promote sustainable development [3], [4]. Today, practical implementation of CE requires a framework and indicators for monitoring and reinforcing positive loops [5]. However, a comprehensive methodology for monitoring CE transition and progress is still lacking, and existing analyses often rely on isolated views that overlook the multifaceted nature of the CE paradigm [6], including social impacts [7].

This Degree Thesis preliminarily explores the effects of implementing a CE strategy in a case study within the manufacturing sector in Italy. Spent Bleaching Earth (SBE) is a production residue of vegetable oil refining, containing 20-40 wt% residual oil and presenting significant disposal challenges, including environmental deterioration (e.g., leaching, groundwater pollution), risk of self-ignition, and increasingly stringent policy restrictions. Traditionally considered a nuisance, SBE has been managed as waste, often through costly solvent extraction treatments [8]. Between 2019 and 2021, the company Sfridoo S.r.l. implemented an industrial symbiosis (IS) initiative for alternative SBE management, promoting its reuse as a by-product in brick manufacturing. IS practices are recognized as key strategies to support transition towards CE [9], and in this context, the SBE generate by a waste producer can find valuable applications in the ceramic industry as a pore-forming agent [10], [11].

Methods

The study assessed the implications of the IS practice across three main perspectives characterizing the circular paradigm: environmental impact, resource scarcity, and economic benefit [6]. Environmental performance was evaluated using the Life Cycle Assessment (LCA) methodology [12], focusing on the Global Warming Potential (GWP) impact category to compare two alternative options for the management of 1 ton of SBE (FU) following a CE strategy (CE-S) or a business-as-usual approach (BU-S) (Figure 1).

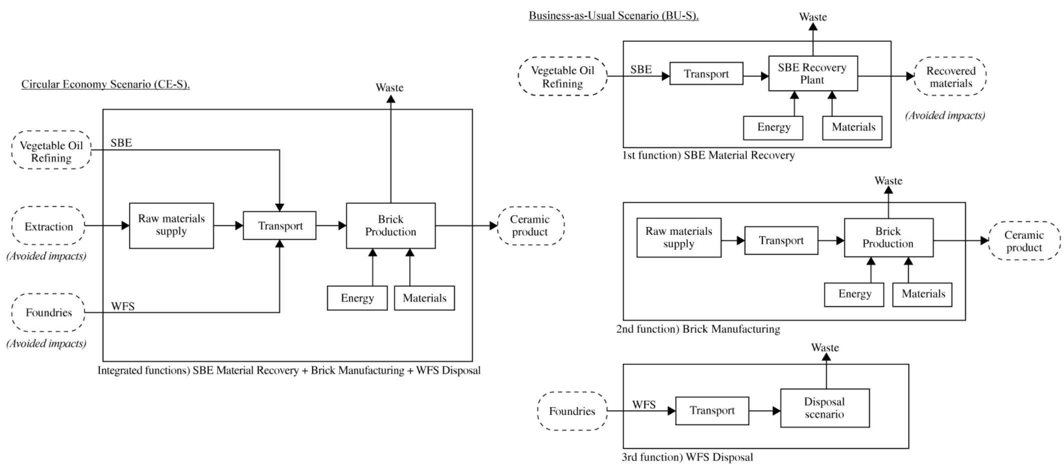

Figure 1. LCA System Boundaries: Comparative Analysis of CE and BU Scenarios for SBE Management

System boundaries were expanded to include all relevant processes and functions [13]. The SimaPro 9.2.0.1 software and Ecoinvent 3.7.1 database licenced to the Dept. of Industrial Chemistry of the University of Bologna have been used to model the system, which has been designed to integrate scientific knowledge, territorial features, market requirements, legal constraints, and industrial stakeholder habits [14]. Avoided impact analysis as well as uncertainty, contribution and sensitivity analysis were also performed to test model robustness. Simple and understandable Circularity Indicators (C-indicators) were developed based on literature [15], [16], [17] to provide insights into resource scarcity and inform business decisions [18]. These indicators have been categorized into two groups based on the system level they focus on (Table 1). The Economic Advantage was quantified to offer suggestions on the financial implications for the original waste producer. This is defined as the sum of the value generated by selling the residue and the savings related to waste disposal and transportation, reduced by the new cost (if any) from the alternative management strategy. Data acquisition was mainly based on public-available papers and supplemented by primary information from by the companies involved. This has been intended to simplify the LCA labour-intense procedure given the preliminary investigation scope.

Table 1. Novel C-indicators for evaluating IS performance from a resource perspective. Author's elaboration based on [15], [16], [17].

Level of analysis	**C-indicator**	**Description**
Company level (micro level)	Recycled material procurement (% of input material)	Percentage of Secondary Raw Materials (SRMs) and by-products coming from other industries that are used in the production process of brick manufacturing
	Waste generation capacity (% of intended product)	Express the amount of waste generated per ton of intended product produced by the Oil Refinery
Symbiotic system level (meso level)	Total waste generation (kg/ton of product)	Amount of waste generated by the companies participating in the industrial symbiosis for producing their products
	Extraction intensity (kg/ton of product)	Total amount of mineral resources purchased by companies each year that derive from mining activities

Findings

The IS initiative set by Sfridoo between 2019 and 2021 is a Repurposing activity (R7) where SBE, a discarded product, is used in a distinct production cycle and with a different function [19]. The transition from waste to by-product extends the lifecycle of SBE, allowing it to serve first as an adsorbent in its "virgin state" and then as a pore-forming agent in its "spent state" after use. Additionally, SBE inclusion increased the use of other waste streams used by the brick furnace into the ceramic blend like Waste Foundry Sand (WFS) and displaced other materials like sawdust and tuff. The CE approach also revealed system multifunctionality, with SBE recovery, brick manufacturing, and WFS disposal managed by the same actor. In contrast, the traditional scenario (BU-S) involved three separate entities to deliver the same output.

– **Performances of SBE management following different scenarios**

The carbon footprint of managing 1 ton of SBE under a CE-S was slightly higher (3%) compared to the traditional approach (5,419 vs. 5,239 kg CO_2 eq. respectively, Figure 2).

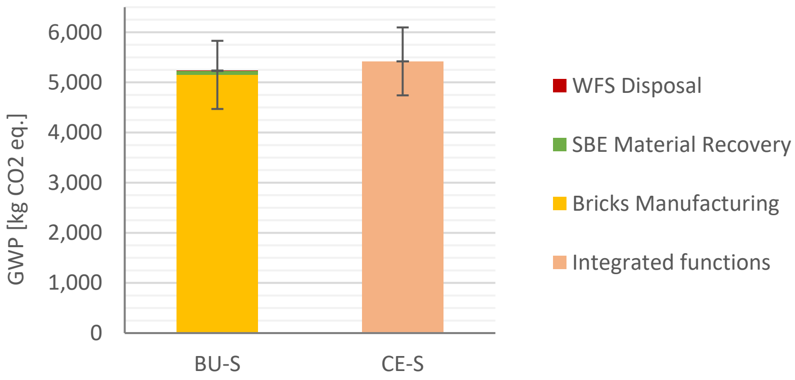

Figure 2. Comparative analysis of functions contribution to the GWP of the scenarios

Despite this, the LCA results do not determine with certainty which scenario is more environmentally advantageous looking at the GWP impact category only. The analysis reveals that avoided impacts, particularly when recovered products displace more impactful goods, can significantly alter this outcome. However, in this case study, the larger emissions associated with the firing step in brick manufacturing, the primary emissions source common to both scenarios, buffered these benefits and potentially overshadowed the variables directly influenced by the CE strategy [20]. Conversely, the economic benefits of SBE conversion from waste-to-resource are significant. Following a CE approach, reclassifying the residue as a by-product reduces management costs of 1 ton to 19.83€, an 83% reduction compared to the initial disposal costs of 116.67€ per ton under the BU-S scenario, with potential annual savings based on the waste producer's production trends of about 116,200€. Resource scarcity is also positively impacted, as adopting the CE strategy led to a 15% increase in recycled material usage and a 48% reduction in waste from the Refinery, while overall waste generation decreased by nearly 20%, and resource extraction was reduced by 4%.

Discussion/Conclusion

This study assessed the impact of a IS initiative that transforms Spent Bleaching Earth (SBE) from traditional waste into a valuable by-product. The strategy showed strong contributions to two out of three key perspectives of the CE framework—resource scarcity and economic benefit—while presenting trade-offs in the environmental impact. While the environmental advantages were not definitive, the approach resulted in reduced resource extraction and substantial cost savings.

Key findings emphasize the importance of LCA in evaluating CE practices, revealing both potential environmental benefits and drawbacks. The reliance on the GWP indicator alone may not fully capture environmental impacts, highlighting the need for a more holistic and standardized approach. Additionally, reclassifying production residues as by-products instead of waste offers clear economic advantages, such as cost reduction and increased profitability. However, the study has limitations, including the potential impact of seasonality on data accuracy and the absence of consideration for social impacts, rebound effects, and economic impacts on the waste treatment and brick manufacturing systems.

The results are context-specific and may vary in different settings. The practical implications suggest that SBE management is a crucial resource. Based on earlier estimates [21] and global vegetable oil consumption data from 2019/2020 [22], SBE generation can be estimated between 2.4 and 3.2 million tons per year. This largely unexplored material warrants further investigation within various production cycles, including brick manufacturing, to foster material circularity and minimize waste generation. In conclusion, the research advocates for integrated, interdisciplinary approaches, and standardized methodologies, and further studies to fully assess the environmental, economic, and social implications of IS practices. These steps are essential for CE effective implementation in industrial contexts and to drive a cultural shift from waste-to-resource.

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Waste management analysis in the province of Palermo: assessment of plant needs

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Abstract

This thesis seeks to determine if existing waste-to-energy plants are suitable to bring an end to the waste management cycle. Otherwise, the use of incinerators would be necessary. Waste management in the province of Palermo passes through the interventions carried out in three optimal territorial areas (ATOs): West Palermo, East Palermo and Palermo Metropolitan City. In the East Palermo ATO, the most important intervention is the multifunctional platform based in the municipality of Castellana Sicula. Similarly, in the West Palermo ATO, the municipality of Corleone has collaborated with the Waste Management Service Regulation Company (SRR) to develop a project for the creation of a multifunctional platform. In addition, the Metropolitan City ATO, in partnership with the Palermo Environmental Resources (RAP), has devised a plan to construct a new organic fraction treatment plant and to enhance the current mechanical–biological treatment at the Bellolampo platform.

Keywords: *Waste; energy; incinerator; intervention; platform.*

Introduction

Waste management within Palermo's provincial territory is carried out passes by interventions in three optimal territorial areas (ATOs): West Palermo, East Palermo and Palermo Metropolitan City. The East Palermo ATO's most significant intervention is the multifunctional waste management platform located in the municipality of Castellana Sicula. The project's core purpose is to create an advanced platform that will reduce the quantity of waste material that is disposed of in landfills. This will enhance the recycling of waste materials. Moreover, the project includes the pre-processing and safety of waste electrical and electronic equipment as well as the pre-treatment of bulky waste [1]. This plant will bring an end to the waste treatment cycle in Palermo East ATO.

Concerning the West Palermo ATO plant, the municipality of Corleone, in collaboration with the Waste Management Service Regulation Company (SRR), has developed a project to construct an innovative waste treatment platform [2]. The project aims to create a reference model for the treatment of fractions of separate waste collection based on a cost-effective strategy as well as the rationalisation and simplification of the urban waste production flow.

The Palermo Metropolitan City ATO, in partnership with the Palermo Environmental Resources (RAP), has developed a project to create a new treatment plant for the organic fraction and to expand the current mechanical–biological treatment plant for undifferentiated urban waste material within the Bellolampo platform, maximising material and energy recovery [3].

The purpose of this thesis is to evaluate the efficiency of existing waste-to-energy plants to establish whether they guarantee the integrated waste treatment cycle. Otherwise, if necessary, the installation of incinerators, which are currently non-existent in Sicily, will be taken into account. This highlights how current waste management systems are particularly lacking and require upgrading to keep up with provincial waste output growth.

Methods

The state-of-the-art waste cycle in Sicily presents challenges. Unfortunately, delays in the application phase of the current regulation, waste management bodies and a lack of a uniform adequate waste management system all prevent high levels of quality and efficiency in service delivery. The specific territorial and economic situation as well as the Sicilian demographic and urban structures should be taken into account, as these all exert a significant influence on waste organisational and management decisions. Inadequate waste management can have non-negligible negative impacts on both the environment and human health.

Disposal practices can lead to serious economic, environmental, social and health consequences that should not be overlooked. Municipal solid waste, as is or after combustion processes, contains various contaminants that pose a health risk. Human incineration plants are also a source of great interest for public health and scientific research, and they remain at the centre of political debates on waste management in Italy. Of greatest concern are the potential effects of individual pollutants produced by combustion processes and released into the environment via the chimney [4].

Understanding how the studies were conducted and the conclusions reached is critical in facilitating the inclusion of heat treatments, which are often a source of concern for citizens, at the end of the waste management cycle. In 2018, a new waste management plan was created for the Sicilian region; the plan intends to define the measures that will improve waste management's environmental efficiency by recognising waste flows, implementing a new integrated management system, assessing the capacity of urban waste management and treatment plants at the provincial and regional levels and planning the necessary infrastructural interventions.

The continuous evolution of European and national regulatory requirements required an initial review of the plan in 2021, followed by an update to adapt it to the most recent National Waste Management Programme of 2022, which is still underway.

Strengthening the waste management system

The second chapter provides a detailed discussion of the area plan updates for the three ATOs. Through these documents, the current plant park was updated [5]. The lack of solid urban waste treatment plants throughout the regional territory and the absence of a facility where waste can be disposed of caused a significant increase in disposal prices. This situation led to problems with health, social and municipal budgets. In recent times, the disposal costs per ton of unsorted waste have risen from an average of 90/€100 to 150/€180, with peaks exceeding €200 per ton. The prices for treating the organic fraction from separate collection increased from an average of 80/€100 per ton to an average of 160/€200 per ton, with peaks of €250 per ton for waste sent outside the region due to the lack of systems [6]. This is a problem that all three ATOs face; therefore, the three multifunctional platforms have been designed to guarantee the necessary treatment capacity in environmentally safe conditions while also complying with current regional, national and community regulations, as well as cost containment and waste tariff [7, 9]. Table 1 explains the predictions above by referencing general data on the various fractions of separate waste collection; it particularly focuses on data from 2017 to 2024 and highlights the point at which 65% of separate waste collection was reached, based on data provided by SRR Palermo Eastern Province. These results were analysed to improve the waste management plant park.

Table 1. General summary of plant requirements (Palermo). Source: SRR Palermo Eastern Province, 13 October 2021

General data	2017	2018	2019	2020	2021	2022	2023	2024
Total collection	593.919	603.438	603.438	603.438	603.438	603.438	603.438	603.438
Waste sorting %	17.27%	19.93%	45.00%	55.00%	65.00%	65.00%	65.00%	65.00%
Waste sorting	102.578	120.261	271.547	331.891	392.235	392.395	392.395	392.395
Undifferentiated collection	491.341	483.177	331.891	271.547	211.203	211.203	211.203	211.203
Organic fraction of municipal solid waste	43.253	54.457	108.619	132.756	156.894	156.894	156.894	156.894
Organic fraction of municipal solid waste % total collection	7.28%	9.02%	18.00%	22.00%	26.00%	26.00%	26.00%	26.00%
Waste from separate waste collection 8%	8.206	9.621	21.724	26.551	31.379	31.379	31.379	31.379

New plant hubs projects

The third chapter presents a brief description of the plant hubs built during 'Project Financing' mode using National Recovery and Resilience Plan (PNRR) funds [1, 2, 3]. All three projects are public utility initiatives with fundamental strategic importance for the waste management cycle in the three ATOs' territories as well as the whole province of

Palermo. The multifunctional platforms will be built in the municipalities of Castellana Sicula and Corleone, while the Bellolampo platform (located in Palermo) will be expanded [1, 2, 3, 8].

Findings

When analysing a fully operational scenario on a provincial scale, as indicated in Table 2, in which the new plants and 65% of the waste collection objective have been achieved, it was observed that the plants have a greater overall capacity than the amount of waste being delivered. However, the capacity of landfills for waste disposal is expected to decrease during a four-year period [4, 5, 6, 7].

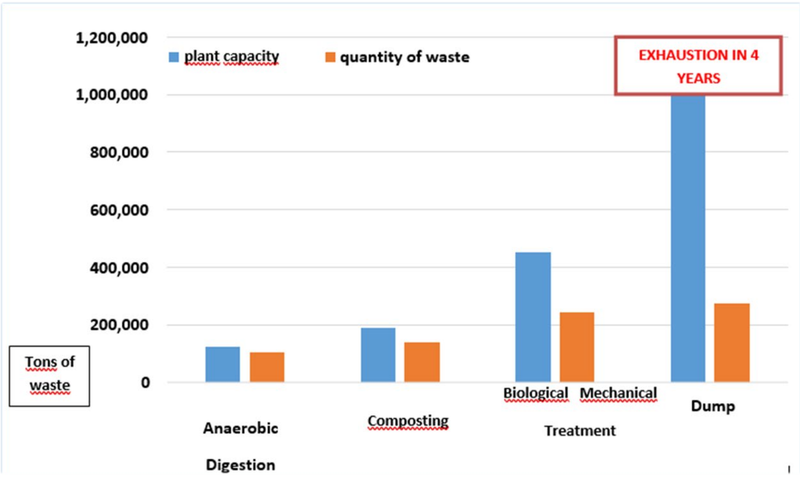

Figure 1. Analysis of the results at the provincial scale

Conclusion

The possible solutions to the plant shortage problem in the province of Palermo are as follows:

- finding an alternative landfill destination for secondary solid fuel and bio-stabilised products derived from mechanical–biological treatment (e.g. external energy use for secondary solid fuel, non-agronomic use for bio-stabilised products by mechanical–biological treatment);
- creating waste-to-energy plants (e.g. one in Palermo – Termini Imerese or Bellolampo area, one in Catania – Pantano d'Arci area) to start the conversion of secondary solid fuel from mechanical–biological treatment or the entire residual urban waste;
- foreseeing a residual volume of landfills to close the integrated waste cycle, which will differ in all three possible solutions [4, 5, 6, 7, 9].

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Life Cycle Assessment of wastewater treatment plant: a case study of Sant'Agostino wastewater plant (Recanati)

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Abstract

The environmental impact of wastewater treatment plants (WWTPs) is increasingly significant due to their energy-intensive operations and contributions to greenhouse gas emissions. This study evaluates the environmental performance of the Sant'Agostino WWTP in Recanati, Italy, before and after a major revamping operation aimed at enhancing operational efficiency and reducing carbon footprint. Using Life Cycle Assessment (LCA) methodologies compliant with ISO standards, the study compares the carbon footprint of the plant's configurations, focusing on Global Warming Potential (GWP) per cubic meter of treated water. Results indicate that the upgraded configuration, which includes expanded biological and sedimentation processes, leads to a higher carbon footprint primarily driven by increased electricity consumption. However, the implementation of a biomass cogeneration process shows potential for mitigating environmental impacts, reducing the plant's GWP by approximately 13%. These findings underscore the importance of integrating sustainable practices like cogeneration in WWTP operations to achieve environmental objectives and support circular economy principles.

Keywords: *Wastewater treatment; Life Cycle Assessment; Cogeneration; Environmental impact.*

Introduction

Due to the growth of various industries and human activities, greenhouse gas emissions have increased the climate change. The negative impacts of climate change are relevant, affecting the availability and quality of water resources. The Intergovernmental Panel on Climate Change reported, in 2017, that the Earth's temperature had increased by an average of 1°C above pre-industrial levels as a result of human activities[1]. By 2100, global mean temperature could increase by 3.5°C compared to the same period mentioned above[2] , with regional average variations of global temperatures between 1.4–5.8°C. It has been investigated that approximately 20% of the worldwide increase in water scarcity will be attributed to climate change[3]. The optimization of energy efficiency in wastewater treatment plant (WWTP) is a crucial issue for managing companies. It is known from literature and managing experience, that, in general, about 25–40% of operating costs of a WWTP is related to energy consumption. The main contributes to energy consumption, in a conventional WWTP, typically are the aeration systems (55–70%), primary and secondary settling with sludge pumping (15.6%) and sludge dewatering (7%). In this context, the study will compare the environmental impacts of a wastewater treatment plant before and after a revamping operation, aiming to evaluate how the changes affect energy consumption and overall environmental performance. Finally, the implementation of a biomass cogeneration process was evaluated to assess the energy saving using the residues of the treatment as biofuel.

Methods

The study focused on the revamping of the Sant'Agostino wastewater treatment plant located in Recanati (MC), Italy, analyzing the environmental impact of a pre and post-revamping configurations. The plant is currently authorized to treat a load corresponding to 14'000 equivalent inhabitants (AE). The major revamping operation involved increasing the volume of the biological tanks and installing two new circular sedimentation tanks. Life Cycle Assessment (LCA) was employed, following the ISO 14040:2021[5] and ISO 14044:2021[6] to compare the environmental impacts of the two configurations in terms of carbon footprint. The LCA was conducted using the SimaPro software, utilizing the ecoinvent database. The impact assessment method applied was the IPCC 2018. Data for both configurations were collected, modeled, and analyzed to evaluate the potential environmental benefits of the revamping process. The aims of the LCA analysis were to evaluate the environmental burdens of wastewater treatment plant in terms of carbon footprint and to identify opportunities to improve the environmental performance of the plants considering the implementation of a biomass cogeneration process. The system boundaries includes all operational units from the initial screening to the final sludge processing. The functional unit was defined as 1 cubic meter (m^3) of treated water. The Life cycle inventory (LCI) process were carried out by collecting data (**Errore. L'origine riferimento non è stata trovata.**) and information about the energy consumed, materials used, emissions and waste generated. In this study, the data collected refers to an entire year of investigation, specifically 2021. To perform the life cycle assessment, the data are scaled to the functional unit. This scaling allows for the comparison of different scenarios: the current configuration and the upgraded configuration of the wastewater treatment plant. Then, the configuration with the biomass cogeneration process was evaluated, considering the 50% of electricity used to run plant was provided by the biomass cogenerator. The complete analysis relate with the operational phase of the wastewater plant excluding from the evaluation the construction phase. The effluent parameter were considered the same for both configurations since the upgraded one is not operational yet.

Table 2. Life Cycle Inventory of both configurations referred to 1m^3 of treated water

Coarse/Fine screening and pumping station	**Current configuration**	**Upgraded configuration**
MSW° [kg]	0.00312	0.00312
MSW transport [kg*km]	0.14046	0.14046
Electricity [kWh]	0.03867	0.03329
Vortex chamber		
Sand [kg]	0.00075	0.00075
Sand transport [kg*km]	0.03371	0.03371
Electricity [kWh]	0.00117	0.00421
Biological and Stabilization processes		
Electricity [kWh]	0.40896	0.36881
Dephosphorylation		
aluminum polychloride PAC [kg]	0.02899	0.02899
Electricity [kWh]	0.00138	0.00126
Secondary sedimentation		
Electricity [kWh]	0.01406	0.02655
Disinfection		
sodium chloride NaClO [kg]	0.00989	0.00989
Electricity [kWh]	0.00019	0.00021
Aerobic stabilization		
Electricity [kWh]	-	0.06946
Sludge thickening		
Electricity [kWh]	-	0.00514
Dewatering		
Muddy sludge produced [kg]	0.12477	0.12477
Liquid sludge produced [kg]	0.21808	0.21808
Transport muddy sludge [kg*km]	7.6	7.6
Transport liquid sludge [kg*km]	1.3	1.3
Anionic polyelectrolyte [kg]	0.00321	0.00321
Electricity [kWh]	0.04314	0.03944
Service instrument		
Electricity [kWh]	-	0.01143
Effluent parameter		
Organic matter as COD [mg/l]	12.3	12.3
Organic substances as BOD_5 [mg/l]	1.8	1.8
Total Kjeldahl Nitrogen [mg/l]	7.6	7.6
Total phosphorus [mg/l]	0.8	0.8
Total suspended solid [mg/l]	5.3	5.3

°Municipal solid waste

Findings

The The results of this study offer a thorough comparison of the environmental impacts associated with the wastewater treatment plant both before and after the revamping in terms of Global Warming Potential (kg CO_2eq/m3), considering the implementation of a cogeneration process. The current configuration produces 0.3093 kg CO_2eq per cubic meter of water treated while the upgraded configuration 0.3309 kg CO_2eq/m3, increasing the carbon footprint of the plant. In **Errore. L'origine riferimento non è stata trovata.**2 the results of carbon dioxide produced are shown for each unit of the plant. The biological processes play the major role in the carbon emission due to the high amount of electricity consumed by the blowers.

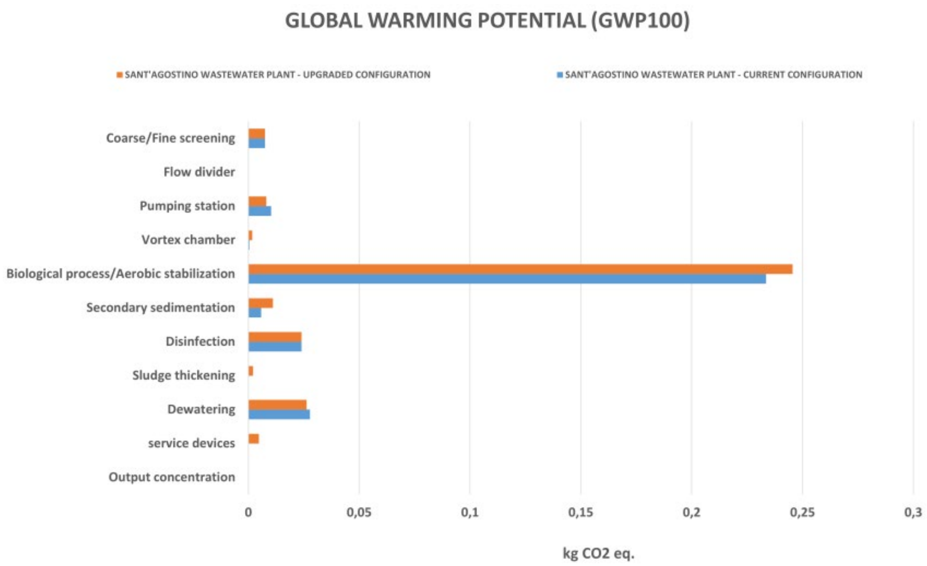

Figure 2. Global Warming Potential - Upgraded configuration

In the **Errore. L'origine riferimento non è stata trovata.**3, the implementation of a cogeneration process is considered in the evaluation of the environmental impact of the plant. In this case, the kg CO_2eq produced by the plant is equal to 0.2876 kg CO_2eq/m^3 while in the upgraded configuration was equal to 0.3309 kg CO_2eq/m^3 reducing the environmental footprint of the entire plant of about 13%.

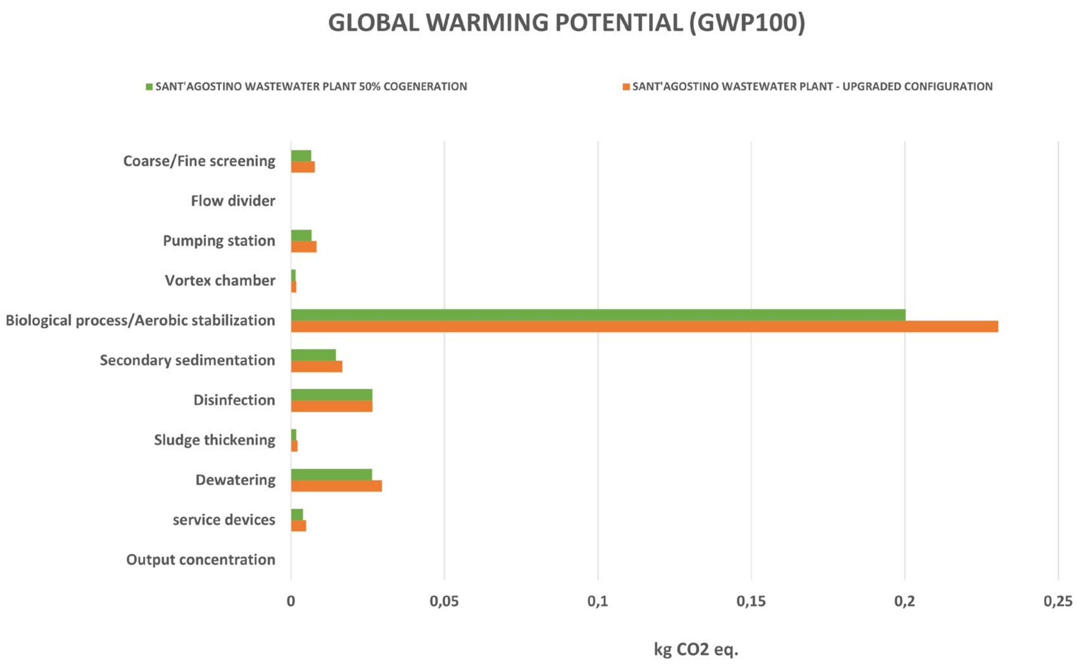

Figure 3. Global Warming Potential - Cogeneration

Discussion/Conclusion

In terms of environmental performance, the upgraded configuration has a greater impact compared to the current one. The interventions on the biological treatment, secondary sedimentation and stabilization treatment are the main drivers of the increasing environmental burdens produced by the plant. The cogeneration process is the solution proposed to the environmental impact issue. In the analysis are not considered the energy demand of the cogeneration plant and its installation. On the other hand, also the reduction in cost and transport associated with the decreased volume of sludge to be disposed of is not included in the analysis. The cogeneration process is a long-term investment aimed at enhancing the plant's environmental performance. It aligns perfectly with the concept of circular economy, where process residues are reused to generate electricity and provide energy for the plant itself.

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Valorization of biopolymers waste through chemical recycling

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Abstract

The purpose of this study was to evaluate the chemical recycling of a biopolymer poly(butylene adipate terephthalate) (PBAT) by glycolysis in order to obtain a product suitable to be used in the preparation of polyisocyanurate foams. A study of the influence of the process variables on the properties of the recovered products has been performed in order to identify the optimal reaction conditions, focusing on the PBAT/glycol mass ratio and the catalyst type. The temperature was maintained in the range 200-210 °C. The results showed that a glycolysis process in presence of dipropylene glycol (DPG), as glycolysis agent, and without catalyst, allows to obtain a product with the optimal properties in terms of viscosity, hydroxyl number and acid value. With this product, polyisocyanurate (PIR) foams were produced with an isocyanate index of 2.5 and an apparent density of about 40 kg/m^3. The foams obtained, even using the 100% of recycled product in substitution of virgin polyols, showed properties comparable with the reference foam obtained with only virgin polyols.

Keywords: *Chemical recycling; Glycolysis; PBAT; Biopolymer; Polyisocyanurate.*

Introduction

Plastic materials pervade our daily lives, serving as the backbone of numerous industries such as electronics, construction, packaging, and healthcare. Their remarkable versatility and unique properties make them indispensable. However, as plastic production and disposal rates soar, concerns about their environmental impact and potential health risks are mounting. Biopolymers have emerged as a focal point of research and innovation because they encompass a wide range of properties; moreover, some materials are derived from renewable resources, some are compostable, and some possess both attributes. Compostability allows polymers to decompose and contribute to compost in natural environments, but does not represent a solution to replace petroleum-derived polymers. So, this research effort to investigate the alcoholysis process of PBAT, an interesting and extensively used biopolymer. The focus lies in exploring various reaction conditions to determine their impact on the resulting glycolysis product properties. Upon identifying of the optimal process conditions, polyisocyanurate foams have been synthesized using progressively higher percentages of recycled polyol [1], enabling an assessment of its efficacy in treating PBAT waste.

Materials and Methods

Materials

The polymer used in this research is PBAT pellets manufactured by BASF SE under the designation ecoflex®. Dipropylene glycol (DPG) were used as glycolysis agents. Industrial grade products were obtained from Sigma-Aldrich.

The catalysts used in the glycolysis are: potassium acetate (KOAc) (99% w/w purity) from Fluka Analytical, titanium butoxide (TBO), supplied by TCI Chemicals, 15% Potassium Hex-Cem®, provided by Borchers and it is mainly composed by potassium 2-ethylhexanoate (KOct), Borchi® Kat 15 which is a catalyst based on zinc neodecanoate (ZnDec), acquired from Borchers and magnesium carbonate hydroxide ($MgOHCO_3$) which is supplied by Merch.

Other materials used in the reactivity tests are terephthalic acid and adipic acid which are two of the three monomers which forms PBAT; they were supplied by Sigma-Aldrich.

Polyols serve as the first reactant in the production of polyurethane foams. We used two industrial mixtures of polyester polyols: Isoexter 4820 by Coim S.p.A. with functionality (f) of about 4.5 and hydroxyl value (HV) equal to 355 mg_{KOH}/g and Isoexter 4941 by Coim S.p.a. with f of about 3 and HV equal to 240 mg_{KOH}/g.

Experimental methods

Glycolysis were done in a pyrex glass flask with a round bottom and four necks. One neck holds a thermocouple, another houses a mechanical stirrer, a third is fitted with a reflux condenser, and the fourth serves as the loading neck. The progress of the reaction was followed by FTIR analysis (Fourier-transform infrared spectroscopy) [2] with a spectrophotometer *Nicolet IS50 Thermoscientific*, while in order to assess the molecular weight distribution of the glycolyzate, we used a gel permeation chromatography (GPC) [3] technique using tetrahydrofuran (THF) as the eluent. To perform viscosity measurements, we utilized a *NμLine* viscometer; the *Mettler Toledo Titrator Compact G20S* was used to evaluate the hydroxyl value (HV) and acid value (AV) of the glycolysis products.

Finally, the produced PIR foams were characterized for thermal conductivity using a *Holometrix Micromet (Netzsch)*; mechanical properties (compression tests), were assessed with a *Galdabini SUN 2500* dynamometer and thermal-oxidative stability was evaluated through thermogravimetric analysis using an *SDT-Q600* instrument. Additionally, we performed morphological characterization through Scanning Electron Microscopy (SEM).

Findings

Glycolisis tests

The glycol and catalyst were poured into the flask and heated to the reaction temperature. The polymer was then introduced at subsequent time intervals to allow the system to compensate for the temperature drop caused by the polymer introduction. The glycolysis process continued for 3 hours, with samples collected at 0, 15, 30, 60, 120, and 180 minutes for subsequent product characterization. Key analyses included viscosity (μ), hydroxyl value (HV), acid value (AV), and GPC determinations.

Table 3 lists the tests made using DPG as glycol and in all tests the ratio polymer/glycol is equal to 2. Several catalysts were tested at different concentrations and one test was done without.

With regard to viscosity and HV, we can see that all the experiments give products that are adequate, because their values are all within the range of desired values. The acid value (AV) is also very important for the use of the glycolyzed product in the foam production. The AV gives an indication of the number of carboxylic groups (-COOH) present: a high AV value could interfere with the catalysts used for the foam's preparation. In fact, one of the catalysts used is an amine, so it is sensible to presence of acids. So, a high AV may cause a worse catalyst activity and at the end the formation of non-performing foams. So, we decided to work with the glycolyzate DPG_2, characterized by a lower AV value.

Table 3. Glycolysis tests using DPG

ID test	Temperature [°C]	Cat.	Cat. conc. *[mmol/100g$_{PBAT}$]*	μ 25°C *[mPa·s]*	HV *[mg$_{KOH}$/g]*	AV *[mg$_{KOH}$/g]*
DPG_2	200	-	-	3300	308	3
DPG_KOAc_2_50	200	KOAc	50	5750	257	8
DPG_KOct_2_10	200	KOct	10	3200	273	12
DPG_ZnDec_2_1	210	ZnDec	5	3200	296	20
DPG_$MgOHCO_3$_2_50	210	$MgOHCO_3$	50	5750	261	15

In the case of the test DPG_2 we did GPC analysis of the sample collected during the reaction time, and the result is reported in Figure . As we can see at reaction time zero, the mixture started eluting shortly after 17 minutes. This is obviously because at the beginning of the glycolysis process, all the formed oligomers have high molecular weight. It is also possible to notice that the peak associated with DPG has the maximum height. Moving forward with time, the reaction progresses: not only the mixture elutes the column at a higher retention time, but also peaks at higher retention time increase in height, confirming the formation of low molecular weight oligomers. Of course, DPG's peak decreases as it is consumed during the reaction. From the GPC analysis, we can calculate, at the different reaction times, the weight averaged molecular weight (M_w), the number averaged molecular weight (M_n) and the polydispersity index (Đ), which is the ratio between M_w and M_n. These data are reported in Table 4. As it can be seen, the molecular weight of the mixture decreases along with reaction time, in particular it is halved in the first fifteen minutes. Then the decrease slows down.

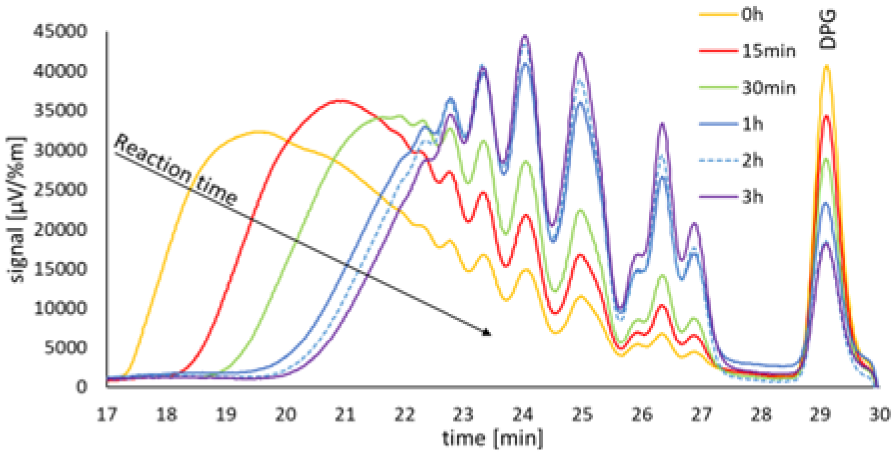


Figure 1. GPC at different reaction times of the test DPG_2

Table 4. Molar weight proprieties at different reaction times

Reaction time [*min*]	M_w [*Da*]	M_n [*Da*]	Đ [-]
0	3758	714	5.3
15	2166	684	3.2
30	1527	621	2.5
60	1234	506	2.4
120	1161	528	2.2
180	1048	491	2.1

Reactivity test

The reactivity tests were carried out at 200°C for 3 hours. Similarly to the glycolysis process, they were performed inside a necked round-bottom flask, with the filling funnel left open. This allowed the water formed during the reaction to easily leave the system. Our objectives with these experiments were to simulate the reactions occurring during the chemical recycling process of PBAT and to facilitate the esterification between a diacid and a glycol, ultimately leading to the formation of water. No catalyst was used in this set of tests. Throughout the experiment, samples were collected at 0, 15, 30, 60, 120, and 180 minutes for subsequent product characterization. Analyses were conducted using FT-IR and GPC techniques. We maintained a mass ratio of diacid to glycol of 0.1. The two acids utilized were adipic and terephthalic acid, while the glycols employed were BDO and DPG. For each diacid, three tests were performed: one with DPG, one with BDO, and one with a 50/50 by weight mixture of both. In Table 5, the summarized tests are labeled as *A_x*, where *A* denotes the type of acid (AA for adipic acid, TA for terephthalic acid), and *x* indicates the type of glycol.

Table 5. Reactivity tests

	AA_DPG	AA_BDO	AA_DPG_BDO	TA_DPG	AA_BDO	AA_DPG_BDO
mass ratio acid/glycol	0.1	0.1	0.1	0.1	0.1	0.1
molar ratio acid/glycol	0.092	0.062	0.074	0.081	0.054	0.065
mass ratio DPG/BDO	-	-	1	-	-	1
molar ratio DPG/BDO	-	-	0.67	-	-	0.67

GPC analysis

The GPC analysis were done for all six the reactivity tests and the oligomers formed were identified and indicated with a lowercase letter in the case of the tests done with adipic acid and with a capital letter in the one done with terephtalic acid. These analyses allowed us to identify three peaks of the glycolyzate produced in the DPG_2 test. Figure shows the GPC analysis and Table 6 shows the oligomers identified.

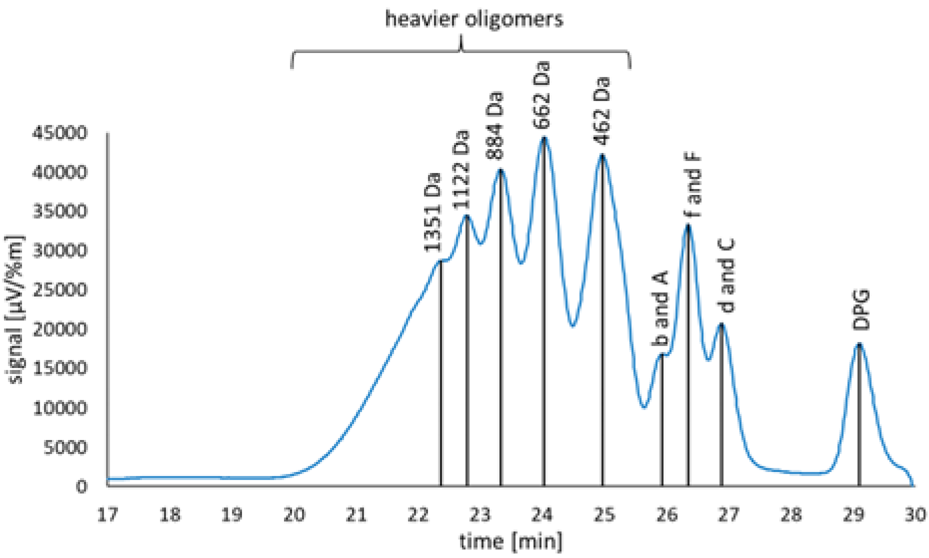
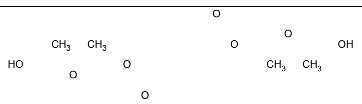


Figure 2. GPC analysis of the test DPG_2

Table 6. Oligomers identified during the reactivity tests

ID	Molecule	M_w [*Da*]	ID	Molecule	M_w [*Da*]
A		398	**b**		378

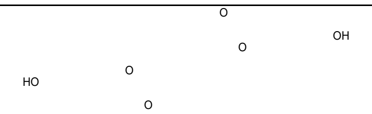
C		310	**d**		290
F		354	**f**		334

Figure shows that oligomers b and A elute from the column at the same retention times, as do f and F, and d and C.

Production of PIR/PUR Foams

A set of PIR foams were manufactured, comprising varying percentages of recycled polyols (25%, 50%, 75%, and 100%) obtained via glycolysis from the DPG_2 test. A reference foam, made from only virgin polyols was used for comparison. After measuring the apparent density, the foams were sawed into one slab for thermal conductivity tests and nine cubes for compression tests. Compression tests were done both in parallel and in perpendicular with respect to the growth direction. The ratio between the two is called anisotropy ratio (abbreviated as aniso ratio). Considering that the compression resistance depends on the density of the foam, each value underwent normalization for comparative analysis, using Equation reported in [4].

The proprieties of the foam are reported in Table 7 and the foams produced are indicated using recycled polyols as "*x PBAT*", where *x* is the mass percentage of recycled polyols used/total polyols and *PBAT* means that we used the glycolyzate DPG_2.

Table 7. Properties of the produced PIR foams

	ρ [kg/m^3]	$\sigma_{//,norm}$ [kPa]	$\sigma_{\perp,norm}$ [kPa]	Aniso ratio [-]	λ [$mW/(m{\cdot}K)$]	d_{cells}[μm]
REF	40.4	318±5	141±4	2.25	25.0±0.2	136±23
25 PBAT	42.9	349±23	160±11	2.18	25.2±0.2	114±18
50 PBAT	42.3	360±26	179±10	2.01	24.2±0.2	103±19
75 PBAT	42.8	353±7	165±13	2.14	23.7±0.2	98±20
100 PBAT	43.6	305±6	167±14	1.83	24.6±0.2	167±31

We observe that the properties of foams produced with recycled polyol closely resemble those of the reference samples. Specifically, $\sigma_{//,norm}$ is consistently higher in most cases compared to the reference, and the thermal conductivity, even in the least favorable scenario, only marginally exceeds 25 $mW/(m{\cdot}K)$, being lower in the other cases. Regarding average cell diameter, derived from SEM images [5] (example in Figure), we notice that increasing the content of recycled polyol (at least up to 75%) decreases the average cell diameter and thus improves thermal insulation and mechanical properties. From TGA analysis there are no significant differences between the foams produced with recycled polyols and the reference foam, so thermal stability was maintained for all foams. These results collectively indicate that the produced foams with recycled polyols maintain a stable structure and possess good mechanical and thermal properties.

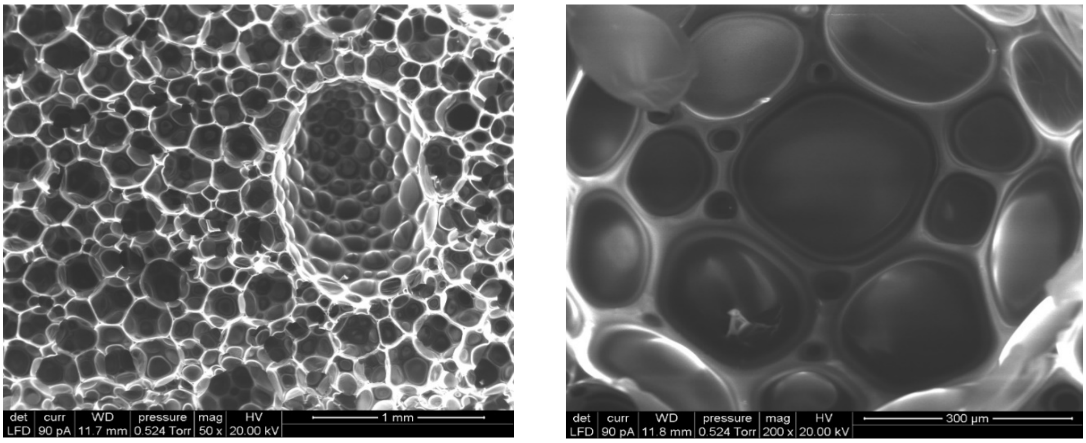


Figure *3*. SEM images of the foam produced with recycled polyol (100%) at two different enlargements

Conclusion

This experimental work extensively investigated chemical recycling of PBAT by employing alcoholysis process. The resulting glycolysis product was utilized in the preparation of PIR foams, followed by a comprehensive characterization of their distinct properties. The experimental results indicate that BDO is not a suitable reactant for PBAT glycolysis; every glycolyzate was solid or semisolid at ambient temperature. DPG exhibits greater activity than BDO. With DPG different glycolysis tests were done with different catalysts. All tests showed favorable results in term of viscosity and hydroxyl number, the only one with a low acid number was the one without a catalyst. This could be attributed to the catalysts' lack of selectivity for PBAT glycolysis and the probable release of adipic acid and terephthalic acid. The glycolysis product employed for foam production entailed a polymer/glycol ratio of 2, a temperature set at 200°C, and omission of a catalyst. To simulate the reactions involved in PBAT's chemical recycling process, we conducted reactivity tests aimed at exploring the products derived from esterification with diacids and glycols, alongside their kinetics.

A set of foam was manufactured, incorporating recycled polyols obtained through glycolysis at varying percentages (25%, 50%, 75%, and 100%). The reference foam, crafted from virgin polyols, served as a benchmark. Foams produced with recycled polyols demonstrated properties closely resembling those of the reference samples and in some case also better. Consequently, it can be inferred from the results that foams utilizing recycled polyols maintain a stable structure, exhibit favorable mechanical properties and thermal conductivity, while also retaining thermal stability. These excellent results are the beginning of a research activity that will continue with other biopolymers.

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CIRCULAR BUSINESS MODELS

Environmental sustainability analysis of different strategies of End-of-Life photovoltaic panels management

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Abstract

The The present paper concerns the analysis of different strategies for the management of end-of-life photovoltaic panels. With this aim, a life cycle assessment was performed to compare the environmental footprint of two innovative solutions (on built on the basis of the best technologies identified in the literature and one developed within the European project Photolife) with the baseline scenario of the disposal in landfilling sites. The analysis highlighted the benefit of recycling (irrespective to the applied technique) and emphasized the environmental gain resulting from the silver recovery enclosed on the innovative process from the literature. The analysis further identified the critical aspects of the treatment, suggesting investments on the integration of renewable energy resources in the perspective of a further improvement of the sustainability level.

Keywords: *Photovoltaic panels, Recycling; Circular economy; Sustainability.*

Introduction

In recent years, the progressive reduction of the cost of technologies and the consequent increase of the efficiency of photovoltaic cells have led to a notable increase in the installation of photovoltaic systems worldwide. At the end of 2019, cumulative installed PV capacity globally amounted to over 600 GW [1]. The growing number of installations has highlighted the problem of managing waste resulting from end-of-life photovoltaic modules. In Italy, assuming a useful life of the modules of 20 years, the modules to dispose of by 2033 (20 years after the peak of installations) will be approximately 18 GW, translated into around 1.44 million tons of modules, which will increase up to 2.8 million tons in 2050 [2]. This estimation may be affected by the variability of the useful life of the panels which can reach up to 30 years. However, the manufacturer's warranty expires after 20 years, due to an overall reduction in generated power of 20% [1,2]. In compliance with the regulations, at the end of their life, the modules must be sent to recycling treatments and must not be disposed of in landfilling sites [1,2]. Current strategies for module recycling include: the mechanical treatment, which involves the removal of the frame and the junction box, the shredding and selection of the materials (which can take place with different methods) and the thermal treatment, which involves the decomposition of the encapsulating material and other polymeric substances [2]. Both the frame and glass are recycled while the cells must be treated by chemical processes that allow the metal extraction and recovery [3]. The treatment can also include all the three processes; in this case, the treatments are defined upcycle processes, that are options with high technological content, able to guarantee the highest value outputs. In this context, it is evident that there is a great attention to the technical aspects related to the recycling of panels [3]. However, the sustainability aspects of the processes are often overlooked. Therefore, this work aims to compare two innovative photovoltaic panels recycling techniques to combine in a single treatment able to produce valuable secondary raw materials.

Materials and Methods

The environmental sustainability analysis was performed to compare two possible options for the treatment of end-of-life photovoltaic panels with a baseline scenario of disposal in landfilling site. The Life Cycle Assessment (LCA) tool, a standardized procedure that allows to record, quantify and evaluate the environmental loads associated to a product, a process or a service, was carried out, according to the standards ISO 14040/44 (2006). The software GABI 9.5, combined with the Life Cycle Engineering database (compilation 7.3.3.153; DB version 6.115) was used as supporting software. The method selected for the analysis is Environmental FootPrint 3.0. The present paper reports the results of normalization and weighting (carried out after classification and characterization) expressed in person equivalent (p.e.), the number of European people (average citizens) that generates the same environmental effect in one year, in terms of impacts from global to local as well the resource consumptions [4]. The analysis referred to a functional unit of 100 tons of end-of-life panels before manual dismantling. The panels considered in the present study have the average material composition reported in Table 1.

Table 1: Average photovoltaic panel composition

Glass	76%
Polymers (EVA, Tedlar)	10%
Aluminum	8%
Silicon	5%
Heavy Metals (Cu, Ag, Pb)	1%

Figure 1 shows the system boundaries selected for the analysis. More in detail, the proposed innovative process was built on the literature basis, combining the best identified operating conditions described below:

- the mechanical-electrical treatment of the panels with recovery of glass, aluminum, silver and silicon wafers [5].
- treatment of wafers for the recovery of nanosized silicon for applications in Lithium-ion batteries (LIB) [6].

These two treatment phases were merged to design a complete recycling process which represents the proposed innovative process. This scenario has been examined to identify the critical phases from an environmental point of view. Furthermore, the innovative solution was compared to the treatment developed within the European project Photolife [7,8] and to the baseline scenario of disposal in landfilling site. As concern the proposed innovative process, some assumptions were made: the energy to mechanically reduce the wafers into ground fragments was considered negligible. A credit of 0 was associated to the polymeric material, suitable to be sent to other value chains. The environmental impact of potassium hydroxide has been replaced with that of sodium hydroxide (considered comparable) due to the data lack in the database.

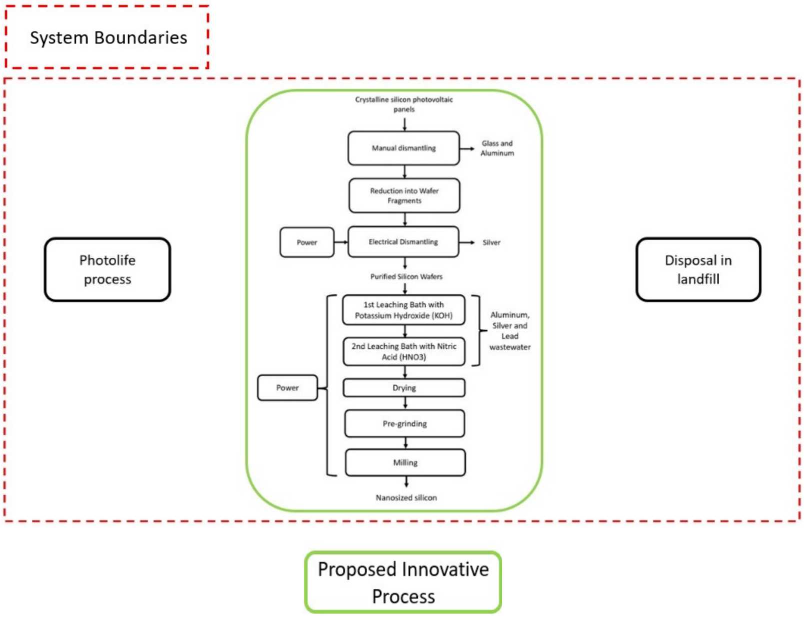

Figure 1. System boundaries considered in the present study

Table 2 reports the mass and energy balances related to the proposed innovative process. As regards the landfilling site, it refers to the disposal of 100 tons. Impacts related to Photolife process were extracted from Pagnanelli et al. (2019) [7].

Table.2 Synthesis of the mass and energy balances selected to perform the LCA of the proposed innovative process - functional unit 100 tons of photovoltaic panels

INPUT	OUTPUT
▪ 100 t of photovoltaic panels ▪ 12 m^3 of KOH 8M ▪ 7.5 m^3 of HNO_3 8M ▪ 24 m^3 of water ▪ 19,500 kWh of electricity consumption	▪ 76 t of glass plate ▪ 8 t of aluminum ▪ 69 kg of silver ▪ 10 t of polymeric materials ▪ 44.5 m^3 of wastewater ▪ 5 t of nanosized silicon

Findings

As showed in figure 2a, both the recycling processes are advantageous thanks to the benefit for the recovered fractions. This aspect also explains the worst result of the disposal since the impact of the management in the landfilling site is combined with the avoided recovery of valuable materials. As concern the recycling processes, Photolife option shows less impact than the proposed innovative process. Nevertheless, the highest sustainability of the proposed innovative process is explained by the greatest credits associated to the additional recovered fractions (mainly Ag) that are able to balance the impact of the process. Thanks to this aspect, the proposed innovative process can reach an environmental footprint up to 3 times lower than that of Photolife option.

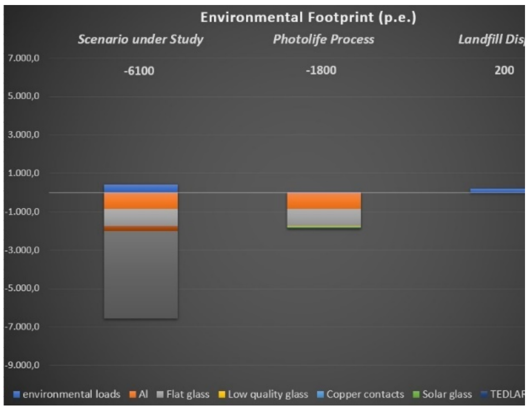

Figure.2a Environmental footprint (p.e.), comparison among scenarios

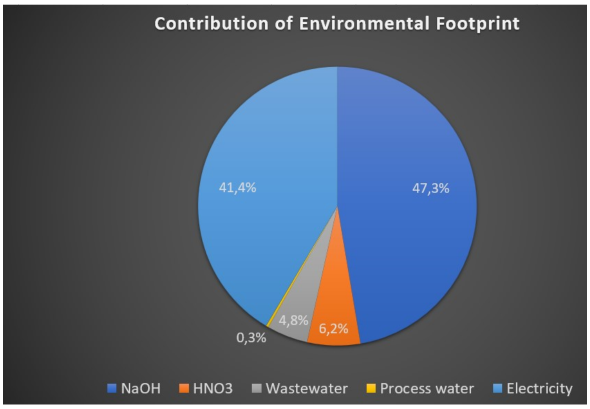

Figure.2b Detailed contribution on the environmental footprint of the proposed innovative process -   functional unit 100 tons of photovoltaic panels

The pie chart in figure 2b provides information on the most relevant environmental impacts on the entire environmental footprint. It should be noted that NaOH, used for leaching, causes approximately 50% of the entire environmental load and electrical dismantling aimed at silver recovery causes 41% of the entire environmental load. Considering the relevance of the use of hydroxides, an integration with renewable energy resources could be hypothesized to reduce the entire environmental burden. On the other hand, the energy for leaching does not significantly affect the impact of the project. Even the energy consumption resulting from mechanical processing is not significant, unlike that linked to electrical treatment for the recovery of silver.

Discussion/Conclusion

Forecasting studies regarding the recycling and future disposal of photovoltaic panels highlight the relevance of developing sustainable solutions for the recovery of strategic raw materials. In this regard, the present paper quantified the possible environmental benefit resulting from the recovery of valuable fractions (e.g. glass, aluminum), irrespective of the selected innovative solution (Photolife vs process object of the study). On the other hand, this environmental sustainability assessment highlighted the issue of an incorrect management of waste panel in landfilling site. Furthermore, the present paper identified a new promising solution (among the proposals available in the current literature) able to enhance the environmental gain of panel recycling, thanks to the additional recovery of the high-value silver fraction. The deep analysis, performed by the effective tool of LCA, also identified the most relevant impacts associated to the process, which could be improved to further increase the sustainability level. In this regard, an integration of renewable energy is suggested to significantly reduce the energy impact, identified as the one of most relevant. Overall, the presented results should encourage in meeting the circular economy requirements and environmental sustainability objectives.

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New materials trends for circular transition. Design of an application for a conscious approach to the sustainable use of materials

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Abstract
The implementation of circular economy principles is a crucial step to improve resources productivity. Thus, to promote a circular use of materials, new business models and new materials developed with sustainability as a main driver are emerging. Designers may play a decisive role in the selection of materials and, consequently, influencing the products-related impacts. The research investigates the main materials classes and their circularity, focusing on the responsibly-conceived ones, collecting and analysing approximately 250 case studies. Subsequently, through an analysis of the main material libraries, the criticalities related to the description of the main materials eco-parameters are identified. The research output consists of a prototype of a digital platform to foster a conscious approach to relevant eco-parameters for material selection and the sustainable use of materials. The platform offers a selection of case studies of innovative materials filed according to a novel framework designed to ensure an improved description of sustainability-related parameters and a set of checklists aimed at highlighting existing correlations among various parameters.

Keywords: *Sustainable materials; Circular materials; Material selection; Circular transition; Ecodesign tool.*

Introduction
The transition towards more responsible production and consumption models is essential to guarantee sustainable growth. Experts [1] and European Institutions [2] agree that the principles of Circular Economy (CE) [3] should guide this transition process to increase the productivity of resources [4] as demonstrated by the novel Ecodesign for Sustainable Products Regulation (ESPR) [5], which entered into force in July 2024. In fact – despite digitisation – today's society still relies on tangible matter to manufacture products; thus, it is crucial to promote a circular use of materials. In a CE perspective, the value of the material should no longer be limited to that of use (i.e. when incorporated into a product), but the material acquires a value *per se* that must be preserved as long as possible, aiming for what Genovesi et al. call "permanent matter" [6]. This circular transition for materials is happening

both with the conceptualization of new business models such as Material-Service Systems [7] and with the emergence of many alternative materials designed with sustainability as the main driver [8, 9]. In the circular transition, designers play a key role since it is estimated that over 80% of all product-related environmental impacts are determined during the design phase of a product [10]. Designers may be responsible for decisions directly influencing sustainability, such as product architecture and material selection. This latter is extremely complex today for two main reasons: the increase in available materials - now estimated at around 160,000 [11]; and the proliferation of properties to be considered including aesthetic-perceptive characteristics and eco-properties [12].

This work investigates how is possible to encourage a conscious approach to relevant eco-parameters for material selection and the sustainable use of new materials developed from a circular and/or sustainable perspective.

Methods

To lay the foundations for the research work, two analyses were conducted with the following respective aims: (1) trace the state of the art of main materials available to designers and their circularity; (2) identify the relevant parameters to describe the circularity and sustainability of a material and investigate how they are treated in materials libraries.

Materials for design and circular transition: state-of-the-art mapping

Many commonly used materials such as metals, glasses, paper and cardboard can already count on recycling and recovery technologies that output a high-quality secondary raw material, making these materials *de facto* circular. For other material classes, obtaining a decent quality of secondary raw material is more complex due to the intrinsic characteristics of the material itself, as in the case of ceramics, fossil-based polymers, woods, textiles and composites [6]. Nevertheless, for these more circularity-critical materials, new recycling processes are being developed that yield better quality secondary raw materials such as chemical recycling for polymers [13, 14] and fibre-to-fibre recycling for textiles [15]. Two aspects that may influence the overall impact of the recycled material and its quality are, respectively, the emissions and consumption related to the recycling process and the origin of the material to be recycled (pre- or post-consumer).

Sustainable native materials: innovative responsibly-conceived materials

Terminological note: for the sake of brevity, the author refers to the new responsibly-conceived materials hereby described using the umbrella term 'Sustainable Native Materials'.

The demands of circular transition gave momentum to the development of new materials expressly designed with sustainability as one of the main drivers and aimed at ensuring lower environmental impacts and improved circularity compared to traditional materials, exploiting one or more strategies. Thus, to identify these strategies and map the landscape of these new materials, a preliminary analysis of approximately 250 case studies was conducted. Case Studies (CS) were selected based on the following criteria: (1) they were recently conceived, mainly within the period 2016-2021; (2) they presented one or more characteristic(s) that may positively affect sustainability and/or circularity; (3) they belonged to different material families (e.g. polymers, composites, etc.); (4) they existed, at least, at the prototype stage. For each CS the following information was retrieved: trade name, manufacturing company, year of presentation or marketing, level of development, detailed composition, application areas, and further characteristics, if relevant. The following strategies to improve material circularity and/or sustainability emerged from the CS analysis: use of renewable feedstocks; use of retrieved/residual resources (by-product or waste); use of low-impact processes (non-energy-intensive, externalities-free, etc.); use of technologies to guarantee material upcycling or limit material degradation; use of Negative Emission Technologies (NET) to operate CO_2 sequestration; offer circular end-of-life options (recycling, composting, etc.).

The CS analysis together with the analysis of previous works on new materials trends [8] allowed the definition of 8 clusters of sustainable native materials based on common characteristics (Figure 1):

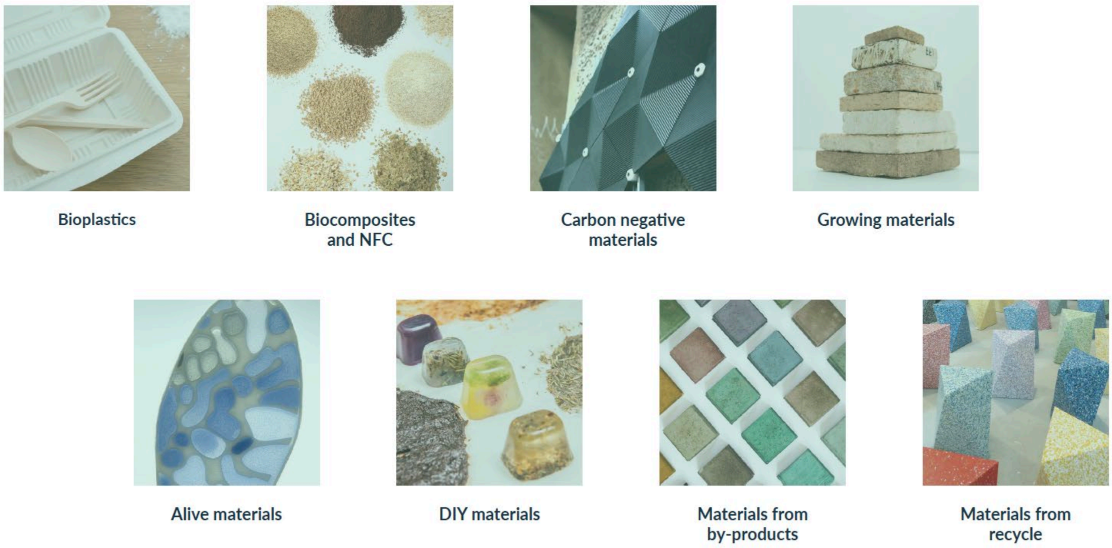

Figure 1. Sustainable native materials clusters

bioplastics [16]; biocomposites and natural fibre composites [17, 18]; carbon negative materials [19]; growing materials [20]; alive materials [21]; do-it-yourself materials [22, 23]; materials from by-products (based on the definition of "*sottoprodotto*" in the Italian legislation, art. 184-bis D.Lgs. 152/06); materials from recycle (based on the definition of "*rifiuto*" in the Italian legislation, art. 183 D.lgs. n.152/06).

Materials libraries analysis

Based on the literature [24, 25] and on the analysis of CS, parameters to be taken into account during material selection to describe the circularity and sustainability in the use of a material were identified. The main ones are the following: origin of raw materials; material composition; impacts and externalities related to the production of the material and the product of destination; end-of-life options and presence of environmental certifications.

Subsequently, an analysis was conducted to investigate whether, how and in what way these material attributes are considered and/or organized within the main existing material libraries. The analysis examined 21 online material libraries. For each material library, it was analysed how these parameters are treated in the selection menus and in the material sheets.

Several critical issues emerged with regard to the treatment of sustainability-relevant parameters: in the menus, they are often not clearly indexed and this makes it complex to refine the search for candidates based on eco-parameters. In the material datasheets, on the other hand, there is often no explicit section dedicated to sustainability; eco-parameters are not clearly distinguished from each other or they are not systematically considered. This makes it difficult to find the information needed to make a sustainability-focused material selection.

Findings

Design of an application for a conscious approach to the sustainable use of materials

Starting from the critical issues identified through the material libraries analysis, a new framework for materials systematisation was developed, aiming at ensuring an improved description of sustainability-related parameters and material circularity. Sections, items and sub-items of the framework are detailed in Figure 2.

Within this new framework, 95 of the 250 previously identified case studies were systematised, selecting those for which sufficient information could be found to fill in the items defined in the framework. In order not to affect the representativeness of the original sample of 250 materials, the proportions of the different material classes were respected, as much as possible, in the 95-case-studies sub-sample (Figure 3). Thus, a database of sustainable native materials was created based on the systematisation framework.

Sections	Items	Sub-items
Presentation	Trade name	
	Company / studio	
	Continent	
	Nation	
	Year	
	Level of development	
	Material class	
	Presentation form	
	Sustainable native materials type	
Sustainability relevant parameters	Composition	
	Origin	Virgin matter
		Recycled matter
		By-products matter
		Bio-based
		Fossil-based
		Mineral/inorganic
		Overall renewability
	End of life	Recyclable
		Compostable
		Energy recovery or gasification from AD
		Biodegradable
		Landifill disposal
	Other certifications	
	Notes on sustainability	
Processes	Forming	
	Assembly	
Properties and characteristics	Peculiar features	
	Properties	
	Aesthetic-perceptual characteristics	Visual texture
		Glossines
		Transparency
	Food contact	
Areas of application	Sectors	
References	Image	
	Link	
	Datasheet	

Figure 1. Materials systematisation framework

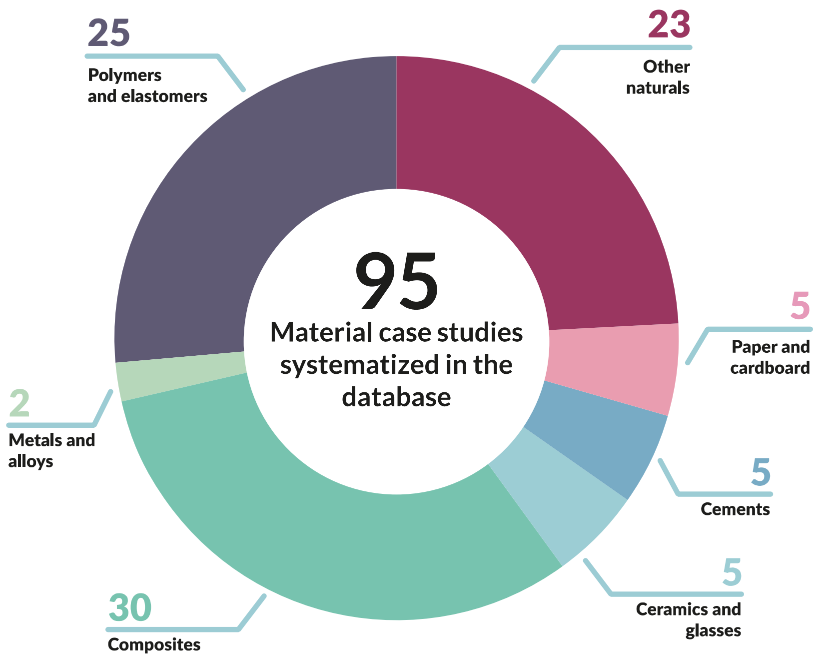

Figure 2. Material classes of systematised case studies

Application design and prototyping

To make the material database accessible to users and provide tools to interpret sustainability-related parameters, a digital platform called SuNMaP (Sustainable Native Materials Platform) was designed and prototyped. SuNMaP demonstration video link is available in the references [26].

Target users of the platform are designers, students, researchers and others into materials scouting such as R&D departments. The platform has two sections (Figure 4): (1) ‘Scopri materiali’ (‘Discover materials’) where the user can browse through the various materials divided by material classes; (2) 'Knowledge & tools' which gives access to 'Sustainability checklist'.

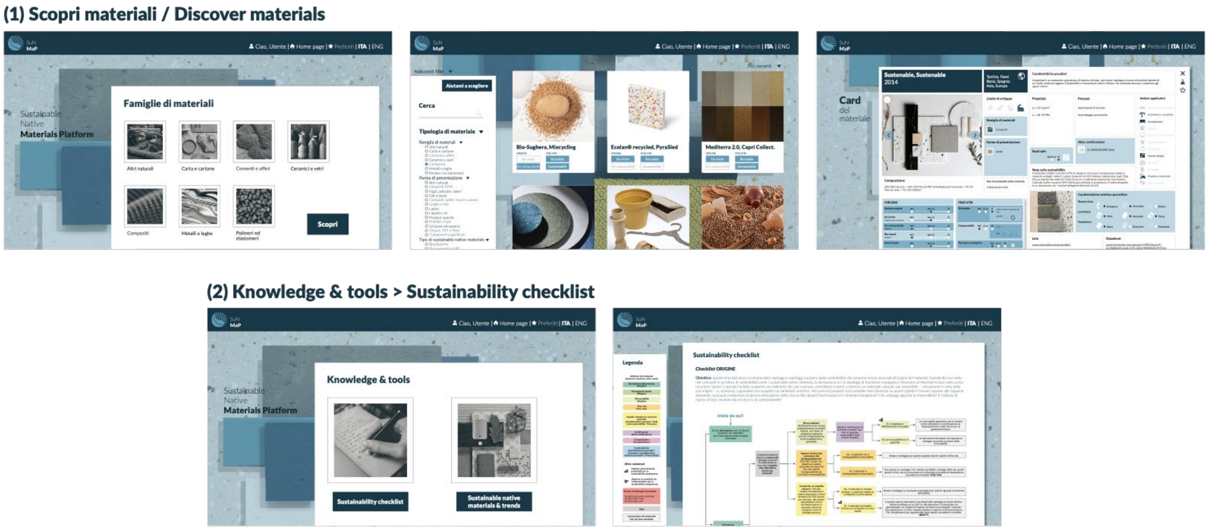

Figure 3. SuNMaP sections

For each material contained in the database a dedicated card was prepared. As shown in Figure 5 material cards are a graphic transposition of the items defined in the framework.

Sustainability checklists have been developed to support users in understanding eco-parameters and highlight the correlations existing among them. These tools also aim to broaden the users' perspective from strictly material-related parameters to others more context-related, such as the type and expected lifespan of the target product, which may influence the overall sustainability of the finished product. Three checklists were developed on the following topics: material origin, material impacts and material end-of-life.

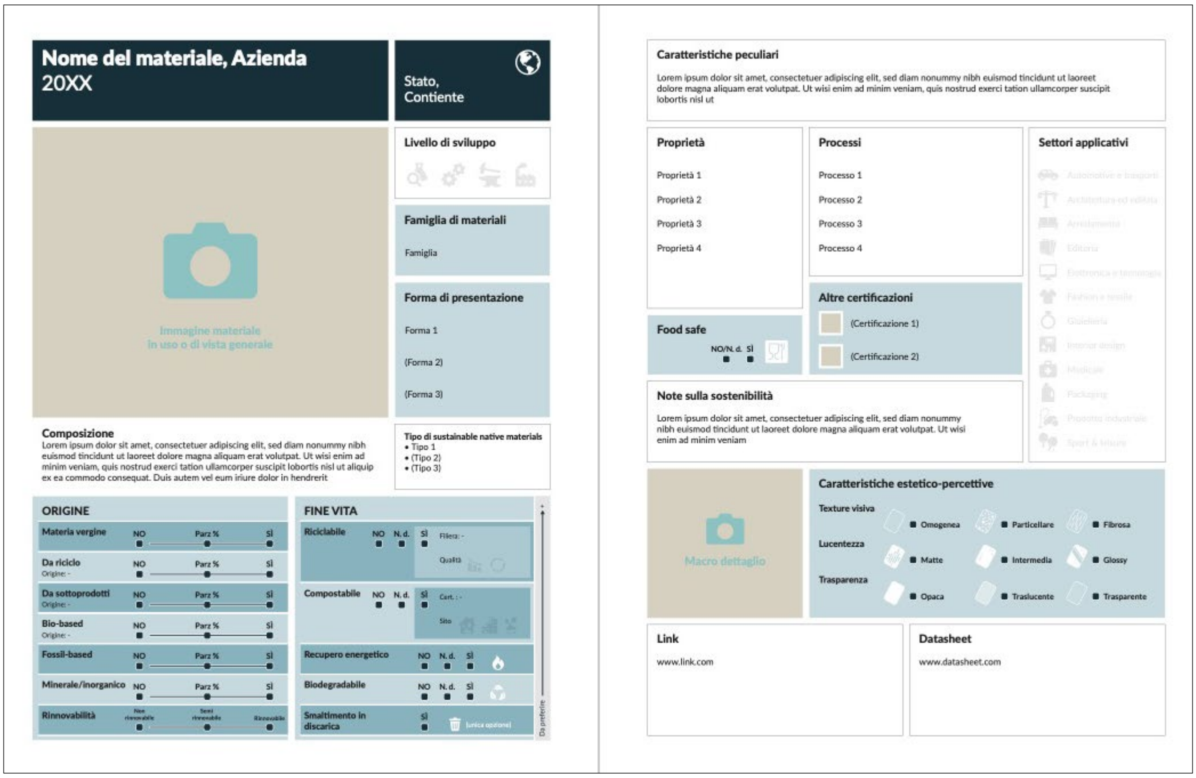

Figure 4. Material cards

Discussion/Conclusion

In view of the results, it can be stated that these new responsibly-conceived materials may provide several advantages; many offer greater circularity by using residual matter and/or features lower impacts (e.g. less energy-intensive processes). In addition to their focus on environmental aspects, these materials often pay attention to the social dimension of sustainability (e.g. job creation in low-income countries).

However, these materials entail some aspects of complexity that should be addressed. Firstly, an *a priori* positive attitude towards the sustainability of these materials should be avoided: the sole being eco-conceived cannot be considered proof of actual sustainability, while is crucial to carefully evaluate as many eco-parameters as possible to assess whether there is a documented upstream company commitment to sustainability. Secondly, the use of these new materials does not always guarantee greater sustainability with respect to traditional alternatives.

In conclusion, can it be said that sustainable native materials are the breakthrough for sustainability? It depends: it is necessary to evaluate each single case, in a specific context and based on the set of parameters identified along the life cycle to determine whether the use of the material is sustainable.

For this purpose, the SuNMaP platform aims to be a qualitative ecodesign tool to support the scouting of new materials based on eco-parameters. However, to obtain a quantitative validation of the impacts related to the use of a material, a Life-Cycle-Assessment (LCA) study must be conducted.

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Review of the GPP regulations and focus on the introduction of minimum environmental criteria for the organization and management of cultural events

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Abstract
The article explores the importance of the circular economy from a political-administrative perspective to promote sustainability in the production sector. A review of European legislation on green procurement is conducted, from the initial communications on sustainable development to the drafting of the Green Deal. Additionally, the Italian legislative history concerning minimum environmental criteria for various product sectors is analysed. The focus is on the events sector, which has recently been influenced by minimum environmental criteria. Various types of environmental impact associated with event management are highlighted, such as air quality, water pollution, resource consumption, impact on flora and fauna, energy expenditure, and waste production. Finally, some literary guidelines that have contributed to defining the minimum environmental criteria for sustainable event management are mentioned.

Keywords: *Green Public Procurement; Minimum Environmental Criteria; Tenders; Sustainable Events.*

Introduction
When discussing the circular economy, the focus is often placed on necessary changes by the production sector, seen as the driving force of economic development. However, consumer behaviour significantly influences supply. Recent discussion on consumers behaviour could not involve the role of public administration as final consumers: they act as end consumers whenever they initiate public procurement tenders. Public administration becomes a consumer that must choose the best product, setting an example. Moreover, when specific conditions are required for bidding, they can direct suppliers to redesign their production systems and improve performance, turning rules into environmental policy tools that promote cleaner and more environmentally friendly production models. Understanding the power of public administration has led to Green Public Procurement (hereinafter referred to as GPP).

Methods
The methodology adopted for this study was based on an in-depth literature review related to the minimum environmental criteria, circular economy, and sustainable public procurement policies. Additionally, active participation in technical tables and

GPP seminars was facilitated through an internship at the former Italian Ministry of Economic Development.

Findings

European Regulatory Context

European regulatory activity for sustainable public procurement began in the 1996 with the publication of the paper "Public Procurement in the European Union" which emphasized the potential of public procurement in relation to the environment and the need to clarify possibilities and limits of incorporating environmental considerations in procurement [1]. In 2001, the European Commission published the Communication from the Commission (hereinafter COM) (2001) 264, which outlined the long-term strategy for sustainable development in Europe [2]. It highlighted public procurement as a tool to accelerate the development of new technologies and recommended better use of public procurement to promote environmentally friendly products and services. In the same year, the Commission published COM No. 274, which analysed the opportunities to integrate environmental considerations in public procurement. In 2003, the Commission introduced COM No. 302, focusing on the "Integrated Product Policy" [3-4]. This communication emphasized the need to integrate environmental needs into public procurement.

By 2004, the directives 2004/17/CE and 2004/18/CE were established to further regulate GPP and provide legal clarity on incorporating environmental factors in procurement processes [5]. In 2008, the European Commission published COM No. 400 "Public Procurement for a Better Environment", aiming to reduce environmental impact, stimulate innovation, identify objectives such as defining common GPP criteria, providing information on product lifecycle costs, and setting political goals with associated indicators [6].

The Commission's objective was to formalize the GPP process, integrate existing criteria, and collaborate with member states and stakeholders. This ensured a common approach to GPP across the EU, avoiding market distortions and competition restrictions. The Commission proposed a toolkit for training and the development of criteria based on existing national and European ecological quality standards. The document identified ten priority sectors for GPP, including construction, food services, transportation, energy, and more.

The Commission committed to maximizing the potential of green procurement through various actions, including disseminating the "Manual on Public Procurement, Research and Innovation", creating an EU system for third-party verification of declared performance.

The European Green Deal in 2019 reinforced the importance of GPP, emphasizing the role of public authorities in setting example considering ecological criteria in their procurement.

Italian Regulatory Context

Before becoming mandatory, GPP was indirectly implemented in Italy in some sectors. In 2006, the legislative decree No. 152 "Environmental Rules" emphasized the country's direction towards sustainable development, stating that public administration should prioritize environmental protection and cultural heritage [7]. The Public Procurement Code of 2006 strengthened the GPP tool by allowing the subordination of economic efficiency to social needs, health and environmental protection, and sustainable development [8]. The 2007 financial law authorized a €50,000 budget to finance the implementation and monitoring of an action plan for environmental sustainability in public administration, focusing on reducing natural resource use, substituting non-renewable energy sources, reducing waste production, emissions, and environmental risks.

The Interministerial Decree No. 135 of 2008 approved the action plan, promoting GPP through various actions like involving relevant national GPP stakeholders, promoting GPP knowledge, defining sustainable purchase processes, setting national objectives, and periodic monitoring of GPP's diffusion and environmental benefits [9]. The GPP's objective was to make "environmentally preferable" purchases one of the highest in the EU. By the time of the plan's publication, Italy ranked eighth in this regard. Legislative Decree No. 50 of April 18th 2016, made the environmental criteria mandatory, emphasizing the inclusion of these criteria in public procurement documentation [10].

The GPP's implementation mainly consists of four phases: preliminary analysis, setting objectives, identifying competent functions, and monitoring. The GPP Management Committee, defines the Minimum Environmental Criteria (known as CAM in Italy) in collaboration with technical working groups of experts and stakeholders to create environmental and ethical-social considerations for each procurement phase. When an agreement has been reached within the working group, criteria are approved by the “Ministero della Transizione Ecologica” and the “Ministero delle imprese e del Made in Italy”. The “Ministero della Transizione Ecologica” and Legambiente established also the "Green Procurement Observatory" to monitor the impact and results of GPP and CAM. The CAM structure is generally consistent across categories and includes the reference environmental standard, purchasing suggestions, and additional bidding indications. The CAM are categorized, and each criterion has a verification section to ensure compliance. The text details the implementation and the specifics of the GPP and CAM, emphasizing its evolution, legislative support, and the methods to ensure its effective implementation across various sectors and regions.

Sustainable management of cultural events

The events sector has become increasingly important in the global economy and, it has both positive and negative effects on the environment. Various environmental impacts can arise when organizing an event or festival:

- Air quality impact: transportation emissions, such as CO_2, CO, and NO_2, significantly affect the greenhouse effect. Noise pollution is also a concern, with the intensity of emissions increasing with the number of participants and the size of the area.
- Water pollution: water bodies near event areas can be exposed to significant environmental impacts related to event support structures and wastewater treatment.
- Natural resource consumption: events accelerate the consumption of natural resources and fossil fuels for transportation, heating, and cooling.
- Biodiversity and local impact: events can affect local flora and fauna and the surrounding environment, especially when the number of visitors exceeds the environment's capacity to handle a large crowd. This can cause pressures on energy use, food supply, etc.
- Food consumption impact: food consumption not only concerns the quantity and waste but also the production methods (soil pollution, chemical fertilizers, etc.).
- Waste generation: waste, mainly from food and beverage packaging, is a considerable environmental impact.

In 2007, *Sherwood* suggested using the "triple bottom line" approach to expand the evaluation of events and promote greater entrepreneurial sustainability [11]. With increasing awareness of climate change, events must become more sustainable to continue existing. It is essential to implement sustainable planning strategies for events, focusing on resource control, waste reduction, biodiversity conservation, and overall environmental conservation. Research has identified six consistent green principles practiced by event organizers worldwide [12]. Particularly, the fifth principle emphasizes "green procurement" or eco-friendly purchasing to reduce environmental impacts [13]. This includes buying event materials from local suppliers to reduce supplier travel and carbon emissions. In Italy, it was estimated that the climate-changing emissions from approximately 23,000 live music events, concerts, and festivals in 2016 amounted to about 1.6 million tons of CO_2. From an economic perspective, the events sector in Italy generates about €65 billion in turnover, directly impacting the GDP by €36.2 billion annually. Italy ranks sixth globally in economic impact from the events and conference sector and employs 569,000 people.

Given the economic and environmental importance of the events sector, many initiatives have been undertaken to develop guidelines and best practices for organizing sustainable events, considering environmental, economic, and social impacts. The "triple bottom line" approach indicates that a company's overall performance should be measured based on its combined contribution to prosperity, environmental quality, and social capital. In recent years, many scholars have expanded research on these topics, with the UNI ISO 20121 standard being the first, developed after the 2005 London Olympics. This standard aimed to guide the eco-sustainable management of major events. In Italy, the Associazione Nazionale Comuni Italiani Lombardia proposed a project in 2016 under European LIFE funding program [14]. The project aimed to disseminate best practices for adopting minimum environmental criteria in the cultural activities sector financed, promoted, and organized by public authorities. After three years of collaboration with various entities, guidelines were developed for the implementation of GPP in the cultural events sector. To improve the environmental performance of cultural events, Italy has introduced minimum environmental criteria (CAM) for events organized by public authorities, as part of the National Recovery and Resilience Plan. The reform aims to enhance the ecological footprint of cultural events by including social and environmental criteria in public procurement for funded, promoted, or organized cultural events.

Discussion/Conclusion

This paper highlighted the crucial role of GPP in the global economy. Italy has a long history of adopting and implementing environmental criteria, leading in this sector within Europe. The GPP tool is pivotal, allowing constant updates to reflect evolving environmental standards. A recent GPP committee meeting on June 23rd discussed regulatory advancements in line with the National Recovery and Resilience Plan's objectives. GPP benefits both the public and private sectors. It rationalizes public spending, promotes a culture of mindful consumption, and boosts the qualitative performance of public administration. For the private sector, GPP supports competitiveness and encourages investment in environmentally superior solutions.

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Extended producer responsibility and competition protection

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Abstract

The growing importance of environmental issues has led the European Union to adopt the "New Action Plan for the EU Circular Economy" to make the production process more environmentally sustainable. To achieve this goal, the EU legislature intends to use an already established tool known as Extended Producer Responsibility (hereafter EPR). However, the plan aims to modify the functioning of this tool in the market by encouraging the proliferation of private waste management companies as an alternative to national consortia. The underlying idea of the new plan is that increasing competition in the waste market will improve service efficiency. The purpose of this study is to analyze the EPR instrument. Therefore, we will break down the EPR mechanism, observe the interaction of different EPR systems, and evaluate the peculiarities of the waste market. Ultimately, perhaps, we will understand if the new EU plan will provide the desired answers.

Keywords: *Circular Economy; Extended Producer Responsability; EPR; Administrative; Industrial.*

Introduction

In 2020, The European Commission adopted the new "Action Plan for the EU Circular Economy". It aims to shift from a market structured around the take-make-consume-throw away model to one founded on the principles of the Circular Economy. This initiative seeks to achieve this transition by fundamentally reshaping the utilization of the Extended Producer Responsibility (EPR) mechanism. EPR facilitates the rejuvenation of products at the end of their lifecycle, diminishes reliance on imports, and influences the design and production processes of consumer goods.

The proposed plan entails moving away from the EPR model established through a national consortium, operating in a substantially monopolistic regime, in favor of a more competitive framework. The crucial question arises: will this approach provide the most effective means to instigate the desired transformation in a market characterized by fluctuating profitability and considerable organizational complexity? This paper aims to address this inquiry comprehensively and shed light on the operational intricacies of EPR.

Methods

To achieve the set goal, following the classic method of doctrinal research, we will begin with a study of legislative sources (to derive the key elements of the EPR structure). In particular, we will derive the key elements of the EPR structure primarily from Directive 2018/851 and Legislative Decree 152/2006. Subsequently, by analyzing sector studies conducted on the waste market, we will seek to understand whether the transition from administrative EPR systems, with a quasi-public nature, to industrial EPR models, characterized by private activity, can effectively promote the realization of a circular economy.

Findings

The concept of EPR (Extended Producer Responsibility) was developed by Thomas Lindhqvist in 1990[1], but the definition generally used to describe it is the one provided by the OECD: "an environmental policy instrument through which the producer's responsibility for a product is extended to the post-consumer phase of the product's life."[2]. It should be specified that such responsibility does not exceed the costs necessary for the operations carried out and that the costs must be allocated, respecting the principle of transparency, among the stakeholders, collective systems, and various public entities.

In 2015, the Juncker Commission adopted a package of measures aimed at initiating the transition towards a circular economy. The Commission's intention was to focus particularly on: (i) product design (aiming to produce goods designed for repair, reuse, and recycling); (ii) reorganizing waste management into a system capable of effectively preventing waste generation, recycling materials, and reducing landfill disposal; (iii) educating consumer awareness[3]. These objectives were spelled out in Directive 2018/851, which amended the previous Waste Directive 2008/98[4].

The instrument chosen to achieve these objectives was EPR (Extended Producer Responsibility). Since it influences product prices, it guides the market and leverages the laws of supply and demand to promote the adoption of production techniques focused on recycling. This is possible thanks to the so-called environmental contribution, the first structural element of EPR, which entails an additional amount added to the selling price, used by producers to cover the costs arising from the management of the post-consumer phase of product life. It is clear that the less these management costs burden the producer, the less the environmental contribution will raise the price of the goods, making the product competitive in the market. And it is precisely this mechanism that directs companies towards eco-design and the restructuring of production and recycling processes.

The most understandable example of this mechanism is represented by WEEE (Waste Electrical and Electronic Equipment). Unfortunately, many of us have likely experienced a situation where a brand-new smartphone falls and breaks. You may have noticed that these phones are made up of relatively few components, typically all of the same material. This construction technique was introduced precisely thanks to the mechanism we are describing. In fact, building smartphones by assembling a few components all made of the same material makes it easier for the manufacturer to recover and reuse the materials, thus reducing recycling costs.

The second structural element of EPR is the responsibility placed on producers. The obvious question is: why is this burden specifically on businesses? In legal terminology, the concept of responsibility has various meanings, but to answer the question, we must analyze the so-called social responsibility. By examining the various definitions provided by scholars, we can state that "in general, this term expresses the increasingly widespread belief that companies must pay attention to a wide range of stakeholders such as workers, consumers, the environment, and the community, as their well-being depends, directly or indirectly, on the characteristic activity of the enterprise"[5]. Such a vision is not new; already during fascism, Asquini spoke of the social responsibility of the enterprise[6]. However, in recent times, it has also found recognition in the activities of various international institutions, as demonstrated by the European Union's Green Paper "Promoting a European framework for corporate social responsibility"[7]. This conception arises from the awareness of the central role that businesses play within today's society and materializes in a new type of governance, where management takes on commitments towards the community and the surrounding environment.

Finally, the mechanism of EPR is composed of two other gears, namely, two principles inherent in environmental law: the prevention principle and the polluter-pays principle. Regarding the former, contained in principle no. 15 of the Rio de Janeiro Declaration and in Article 191 of the Treaty on the Functioning of the European Union (TFEU), it expresses the need to first and foremost take preventive actions regarding events that will certainly lead to environmental damage[8]. Thus, it justifies the responsibility of the entities that, being upstream in the production process, are in the best position to prevent waste production. The polluter-pays principle originated in the OECD recommendations of 1972 and 1974[9] and is now contained in Article 191 of the TFEU[10]. Over time, it has taken on the character of a general legal obligation, assigning to entrepreneurs the expenses for preventing and remediating the harmful effects produced by their activities. Its dual nature, both punitive and preventive, undoubtedly makes it the soul of EPR.

Having identified the essential and universal components of EPR, it should be highlighted that, in our continent, this instrument has found varying forms of application from one legal system to another[11]. In fact, European legislation, through Directive 2018/851/EU, merely establishes a series of minimum requirements for EPR systems, leaving it up to each member state to determine the internal operational modalities.

Therefore, to date, EPR systems manifest in many forms, even within individual legal systems and even regarding the same type of waste; hence, to make a comparison, it is necessary to establish parameters that are useful for identifying the archetypes to be compared. To do this, we will use the classification proposed in Professor Andrea Farì's lectures, analyzing the systems based on the criterion of 'administrative dimension'[12]. We will then compare *administrative systems* with *industrial systems*. Thus, we will call *administrative systems* those that, arising from direct legislative provision, operate in a position reminiscent of that of administrative bodies (see the Italian example of CONAI). On the other hand, all those systems born from private initiative and that at no stage of their history enjoy a privileged position in the market belong to the category of *industrial systems* (for example, For example, the German Dual System Deutschland, known as DSD).

A first difference that emerges when applying these parameters concerns the composition of the systems themselves, as administrative ones show an aggregation of economic operators that is strongly heterogeneous compared to the typically homogeneous composition of industrial systems. This discrepancy clearly stems from the historical-cultural context of the sector in which the entity forms. It is enough to consider that *administrative systems*, unlike *industrial* ones, arose in a context that did not consider waste management a profitable activity, thus requiring legislative intervention to create an entity that is tendentially monopolistic and devoid of profit-making purposes, in order to ensure the protection of a public interest. A clear example is the Cobat consortium, founded in 1988 in Italy to manage used batteries and lead. Initially, recycling was less economical than buying new lead due to low lead prices. Thus, Cobat was established as a mandatory consortium to support lead waste recovery. However, from 2006 onwards, rising lead prices made recycling more desirable. Complaints about Cobat's monopoly led to legislative changes, allowing entrepreneurs to join alternative consortia.

Another element that differentiates the operation of these two models is that autonomous systems are subject to greater public control. For example, in Italy, the law subordinates the existence of an *industrial system* to an evaluation by the Ministry of Environment and Energy Security regarding the conformity of the statute to the ministerial model and the ability of the entity to ensure the achievement of the environmental objectives set by the legislator. On the other hand, *administrative systems* are fundamentally devoid of management controls.

The choice between directing the waste market with an *administrative system* or an *industrial system* represents the distinction between a market that is tendentially monopolistic or competitive. Therefore, the crucial question is: can an increase in competition between EPR systems lead to greater efficiency in achieving environmental standards?

On one hand, "semi-public" systems can operate outside of entrepreneurial logic and market fluctuations, ensuring a minimum standard in environmental care. Additionally, they serve as a simplification element in coordinating all sector operators. On the other hand, various studies, such as the OECD's "For an Effective Waste Management" guide (2018) or a study funded by the Canadian government in 2018[13], advocate for the utility of a more competitive context. Furthermore, if alongside the environmental issue, the protection of the market's competitive structure is considered, it is evident that the proliferation of *industrial EPR systems* appears more suited to reconcile these two interests; which, as Professor Giampaolo Rossi teaches us [14], are not necessarily conflicting.

Discussion/Conclusion

In conclusion, we have examined why Extended Producer Responsibility, by acting on producers and leveraging market mechanisms, emerges as the ideal tool to promote and strengthen the circular economy. Subsequently, we have explored how the burdens imposed by EPR on businesses are addressed through organizations created by national legislators or by the obligated parties themselves. Similarly, we have understood that the effectiveness of these systems is conditioned by various factors that go beyond mere organizational structure.

Indeed, we can affirm that the form adopted by the entities operating within the Extended Producer Responsibility framework does not represent a sufficient element in itself to determine the levels of waste recovery and recycling that the system will achieve.

In particular, the findings of our study clearly highlight how the level of success achieved by an EPR system strongly depends on elements belonging to the economic and social substrate, such as: the cultural readiness to take responsibility for waste management operations, the economic viability of raw material recovery, or the entrepreneurial initiative of operators in that sector. This conclusion is supported both by scientific surveys, such as the mentioned McKinsey study, and by empirical deductions. A clarifying example is certainly the market for used tires: in Italy, this sector is characterized by the operation of associations of private individuals in free competition, while in Belgium, a national consortium operates. Despite the two opposing approaches, both achieve excellent levels of efficiency, and the same applies to most segments of the market.

Therefore, looking towards the future and the objectives of the European strategy for achieving a circular economy, such as resource efficiency, reduction of greenhouse gas emissions, and compliance with the European waste hierarchy, it seems desirable to encourage a more systematic approach regarding environmental policy instruments. It is evident that the efficiency of the new EPR regimes will be conditioned by the support of additional instruments that the legislator may want to adopt to regulate the sector, such as precise regulations on product design. Furthermore, the adoption of appropriate fiscal measures and the increase in consumer awareness and education initiatives will be crucial.

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10. Il principio «chi inquina paga» è stato successivamente enunciato in ambito comunitario nel Primo Programma di Azione Ambientale del 1973, mentre la prima definizione normativa si deve alla Raccomandazione del Consiglio 75/4367/Euratom, CECA, CEE, in GUCE L194, 25 luglio 1975. Nel trattato di Maastricht è sancito all‟art. 175, par. 5, TCE.
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A design driven approach to reducing household food waste with AI: engaging the stakeholder's cooperation for sustainable management

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Abstract
This study investigates if artificial intelligence (AI) is a valid tool for reducing the environmental impact of household food waste (HFW) and benefiting stakeholders in the food industry (FI), also exploring the role of designers in this context. AI is one of the innovative technologies applied to counteract HFW-generating behaviors. It can simplify stakeholder cooperation by providing results that address their needs. Market analyses and case studies highlight the crucial role and potential for retailers in reducing HFW. Implementing AI services in grocery business models could optimize household scheduling and meal planning, despite current technological limitations. Retailers from this system could benefit by enhancing their purchase forecasting, minimizing in-store waste, and increasing customer loyalty. For designers inducing AI into the framework will make them become more problem-solvers by automating the iterative process. The result consists of design guidelines for an AI-service suggesting using behavioral change theories for an ethical application.

Keywords: *Artificial intelligence; Household food waste; supply chain; Stakeholder cooperation; Ai service design.*

Introduction
Unconsumed food wastes all the energy and emissions associated with its production [1]. The impact at the household level is considerable, with an annual per capita production estimate of 74 kg [2]. HFW generation is influenced by multiple factors, making it challenging for consumers to track and manage it effectively. They are often unaware of their environmental and economic behavior consequences [3, 1]. Therefore, the literature demands design-led solutions [4], preferably by intervening in upstream steps like planning and management. Innovations in user experience and technologies offer promising avenues for improving household food management. Some techniques try to extend food conservation, such as increasing packaging performance and using RFID sensors. In contrast, others focus on management solutions like mobile applications, smart fridges, and the use of AI [5].

Figure 1. Practices that lead to household food waste generation [6]

Therefore, this study aims to identify new sustainable solutions for HFW reduction from a circular economy perspective by answering the following research questions:

- (RQ1) Can AI be a sustainable and supportive tool to decrease the amount of HFW? (RQ2) Can developing an AI-service to reduce HFW bring value to stakeholders in the FI supply chain?
- (RQ3) What is the role of designers in reducing HFW through the application of AI?

This study will provide a new perspective for FI stakeholders involved and providing guidelines for designers suited to develop innovative solutions to reduce HFW.

Methods

To answer RQ1, a literature review was conducted on HFW drivers and solutions, Industry 4.0 functioning, AI technology, and cutting-edge technologies used in FI applied to packaging, household appliances, and mobile applications. To address RQ2, this information was incorporated into a market analysis to collect quantitative and qualitative data on mega and industry trends, case studies, and consumer perceptions. This study, in particular, entailed a survey of 160 Italian participants from the four generational groups regarding their food waste (FW) behaviors, attitudes, and preferences for an AI-service. Lastly, RQ3 searched the literature for AI applications in service design and FW reduction. Databases used included Scopus, Science Direct, and Google Scholar. The collected insights informed the development of new design guidelines.

Findings

AI as a solution for reducing HFW

The phases of the food supply chain are strongly connected. In this regard, many studies and market solutions convey that a promising way to reduce HFW is through the cooperation of stakeholders [7]. Each actor in the supply chain has its own needs and intrinsic complexities. Collectively, addressing these problems would reduce waste but could pose challenges in handling all this information. AI is the ideal tool because of its ability to manage a great amount of data [8]. Therefore, applying an Industry 4.0 approach [9] and utilizing AI to streamline data exchange will help develop sustainable solutions tailored to each FI stakeholder. In particular, a concrete answer to (RQ1) is found in several applications that have already shown results in FW savings at the first steps of the supply chain, while investments are increasing at the latest phases [10].

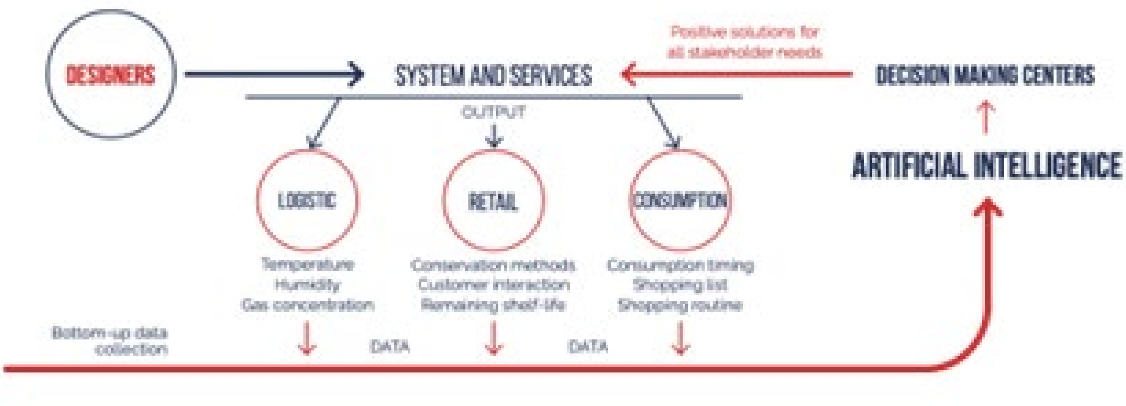

Figure 2. Industry 4.0 bottom-up data collection approach, adapted from [9]

The key role of retailers in reducing HFW while gaining market share

Market trends outline a favorable scenario for services aimed at reducing FW for customers. In 2023, the use of generative AI technology rocketed, resulting in many organizations creating personalized experiences [11], like the chatbot Hopla implemented by Carrefour in its e-grocery to streamline purchase steps, reducing meal planning efforts [12]. Additionally, consumers now demand more attention to emissions and sustainability, seeking concrete data on improvements [11]. On the other hand, field trends are related to inflation, which has driven more customers to discount stores and private-label products, urging large retailers to increase customer loyalty, particularly by leading them to save money [11]. While, the growing adoption of smart refrigerators, which manage inventory and create shopping lists via apps, represents another trend that offers a new sales channel for supermarkets, currently dominated by online grocery tech giants [13]. A remarkable example is Tesco UK for FridgeCam.

The supermarket tries to eliminate the manual inventory compiling of ingredients and expiry dates typical of smart fridges by providing the owner of the device with data about the bought ingredient expiry date. This service boosts loyalty, as those who own the cam but do not shop at Tesco lose some functionalities while current customers are likely to continue buying to keep their inventory updated [14]. The answer to (RQ2) identifies that retailers can help reduce HFW, creating business opportunities verified by market research, with the outputs summarized in Figure 3. Introducing a service that, through the Internet of Things (IoT), can collect data on the habits of consumers or monitor the deterioration status of food and later allow generative AI to process these data to provide recommendations for scheduling, meal planning, and purchasing based on the precise needs of the family communicated by the latter. This service provides concrete assistance in all the phases that contribute to HFW generation shown in Figure 1, which are increasingly difficult to keep in mind in the hectic life of today.

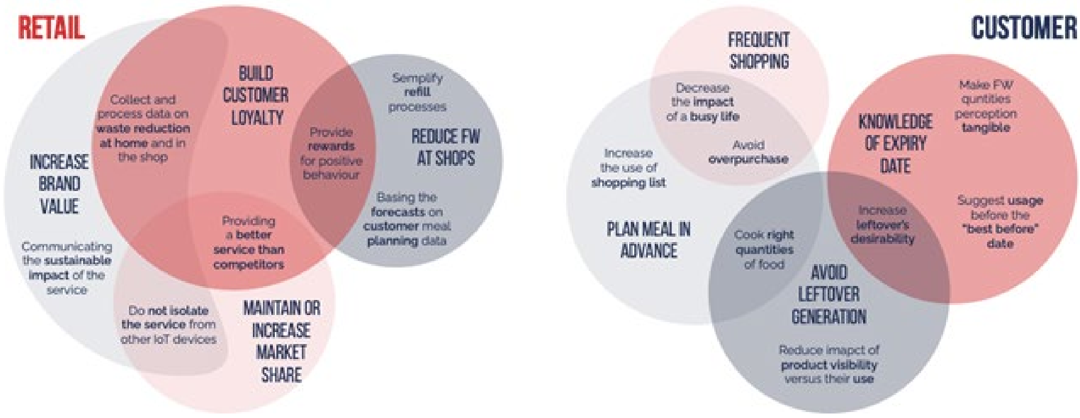

Figure 3. Market analysis for retailers and customer convenience for reducing HFW

The role of designers

To address RQ3 has been found that designers intervene in the bottom-up approach as developers of services and systems that collect and redistribute data or outputs. Indeed, to generate a positive difference in the FI, they must first apply persuasive design for behavioral change techniques to guide users to the correct behavior by rewarding the correct execution [15]. Secondly, be aware of the AI potential in the FI namely: link data, span boundaries, build relationships, and create a knowledge infrastructure [16]. However, there are ethical implications, these professionals must advocate fairness, transparency, and accountability, in data collection and usage [17]. As far as AI is bringing changes in service design, its introduction in customer experiences is not yet predictable, especially regarding reactions and expectations of people [18]. Despite this, the design framework will not vary much because iterative processes will remain, but with the advent of AI, it will be accelerated by "problem-solving loops" typical of deep learning. It will increasingly transform the role of designers into problem-finders rather than solution-makers [19, 16].

Design with AI: Exploring Customers opinions and fears about the AI-service

Italian respondents questioned about the utility of the AI-service with the purpose introduced at the end of 3.1.2 show a high appreciation by 48% of Gen Z and 36% of Millennials, while inverse perception is recorded for the older generations. Similar results came for the consistency of usage. This is because knowledge about planning, cooking, and food management decreases accordingly with age. Fear about sensible data sharing is not predominant for this application, and those who feel it the most are Gen X, whereas, for Gen Z and Millennials, it is a practice that generates no fear concerning the described benefits. Favorite characteristics of the AI-service emerged are that it can help save money and time, and reduce their CO_2 impact. The least liked features are functionalities only available for payment and requiring ownership of a smart fridge to use it. Regarding usage, entering needs-related inputs is tedious, and people would not like to do it through chatbots and mobile applications. This new AI-service corresponds to going from processing mentally all that information to compose the shopping list, to having a digital inventory that can simplify planning, shopping, and cooking. Unfortunately, from the survey, the service proposed seems not to be compared to a “smart shopping list”. Therefore, designers will likely need to emphasize these usability and communication points to make service usage more fluid and to implement a reward that will lead to correct behavior.

Designing guidelines

The research output is design guidelines for an AI-service to be incorporated into the business model of supermarkets to reduce FW. The process involved fostering cooperation among diverse stakeholders to facilitate the sharing data on household consumption, retail inventory, and production needs. Personalization emerged as a fundamental factor for users, necessitating consideration of their habits, dietary restrictions, and preferences, addressing exceptional situations. Emphasizing the communication of personalized benefits, such as cost and time savings, is identified as key to effectively engaging users. Additionally, enhanced convenience is recommended to simplify user interactions with the service, ensuring minimal effort for maximum benefit. Ethical considerations are deemed paramount, highlighting the importance of respectful data gathering and use, adherence to regulations, and the preservation of freedom of choice for consumers. Finally, attention to user experience, acknowledging the diverse perceptions of AI introduction based on factors such as age, education, and knowledge, and trying to keep the functioning and appearance of the service consistent even if the data-gathering technology changes, is crucial. By adhering to these guidelines, AI-driven solutions can effectively tackle FW while enhancing user satisfaction.

Figure 4. Design guidelines for a new AI service offered by grocers to their customers

Discussion/Conclusion

AI represents a promising tool for reducing HFW at the upstream phases of its generation. Retailers stand to gain advantages by offering AI-driven services to their customers, including brand enhancement and improved sales forecasting that will positively impact the supply chain. Unfortunately, technology limitations in RFID applications and blockchain do not allow the collection of all the data needed to apply the guidelines. Moreover, designing services with AI does not deviate significantly from conventional frameworks. However, reactions to AI introduction in services will generate unknown possibilities that must be explored and tested in the future. Additionally, research is needed to assess the balance between the CO_2 emissions associated with AI technology and the environmental benefits derived from HFW impeded. To complete the overview, technologies such as augmented reality and blockchain applied to HFW reduction should be further explored. In conclusion, the introduction and design of such services must follow an ethical approach to data collection and use, ensuring that this technology serves as a tool for the circular economy and not only for marketing purposes.

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A novel methodology for evaluating citizens'shared responsibility in sustainable consumption choices: textual analysis through MADIT

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Abstract

This research examines the role of human interaction in sustainable resource management in current climate change. It highlights the need of a clear, rigorously founded definition of "sustainable consumption", to commonly assess the value attributed to resource use by citizens. Based on the theoretical-methodological framework presented, the research's aim is to assess shared responsibility in resource use among citizens of the Veneto Region, Italy. To achieve this, two citizen profiles are identified: stakeholders, who prioritize personal interests, and communityholders, who pursue shared goals. MADIT methodology is used to analyse interactive-discursive modalities and measure shared responsibility by employing the sustainable consumption index described. The results show a medium-low level of shared responsibility, suggesting that Veneto citizens mostly interact in a stakeholder position in their resource use. Based on this, the research highlights that citizens tend to contribute minimally to co-responsible resource use and management, displaying its impact on social cohesion.

Keywords: *Sustainable Consumption; Shared Responsability; Social Cohesion; Climate crisis; MADITl.*

Introduction

The focus on human activities' role in climate change has highlighted the importance of sustainable resource management to mitigate global warming. Key policies aim to ensure sustainable production and consumption of available resources, both material and immaterial, to reduce the human impact on climate emergency [1, 2]. To achieve this, citizens engagement in terms of responsibility in using resources is crucial [3, 4]. On the topic of sustainability, comprehensive studies on social dynamics are lacking and reveal a key issue: the absence of a clear, rigorously founded, and universally accepted definition of "sustainable consumption" [5].

Operational, and therefore governance, definitions adopted often blur the line between resource consumption and use, leading to confusion, misinterpretations and overlays. This is because consumption implies resource depletion, being oriented towards an end for the sake of it, and potential human species extinction, while use can involve resource renewal (re-use) towards human species conservation. This confusion hinders the creation of common indicators and clear guidelines for action. Without a precise and shared definition, it's impossible to measure how citizens attribute value to resources, how this value changes, and how such changes can be sustained or modified. This complicates the assessment of citizens' shared responsibility in managing climate crisis-related challenges, in terms of how they contribute within the community in referring to a common goal (e.g. global warming mitigation) and in defining shared strategies to reach it (e.g. resources use), thus impacting on social cohesion. Politically and administratively, this also creates uncertainty now and in terms of anticipating how future resource use impacts on the community [6, 7].

Addressing this, the emerging need is to delve into the processual dimension of how citizens attribute value to resources use (both material and immaterial), i.e. how they responsibly contribute to the management of the impact of daily choices on climate change. The proposed contribution consists of an innovative theoretical-methodological framework to study, assess and measure the degree of shared responsibility among Veneto Region citizens (Nord-Est Italy) in resource use through an *ad hoc* designed survey.

Methods

THEORETICAL AND METHODOLOGICAL FRAMEWORK

Theoretical Assumptions

Adopting Dialogic Science theoretical framework [9, 10], we distinguish two different citizen profiles: stakeholder and communityholder [8]. On one hand, as a stakeholder, the citizen interacts in the community primarily with the aim of safeguarding his/her own personal interests. Their interaction modalities used to attribute value to resources lead to consumption, so there is a risk that they may become depleted, which could eventually result in economic crises, conflicts and, ultimately, our extinction. This way of interacting leads to social fragmentation and hinders the formation of a cohesive community. On the other hand, the communityholder citizen interacts within the community by pursuing common and shared goals. These citizens use resources in a generative ("sustainable") way, configuring their role as a co-responsible contributor in the community, promoting efficient resources lifecycle management, their availability in the future and, therefore, the common goal of preserving our species. S/he fosters and enhances social cohesion and responsibility, steering the community towards shared goals.

Based on these theoretical assumptions, the concept definition of sustainable consumption used here is: "The set of interactive-discursive modalities that implies shared responsibility, of the entire human community (in a Communityholder dimension), in attributing that value to material and immaterial resources that, anticipating the repercussions in terms of production and consumption, promotes the conservation of the species". According to this definition, sustainable consumption is the use of resources that anticipates potential impacts on human species both during production and consumption. It involves the configuration of resource use and its value generated within the community, in terms of shared responsibility. Here shared responsibility pertains to each community member's contribution to social cohesion and the common goal of human species preservation.

Methodology

To study the interactive-discursive modalities employed by Veneto citizens to configure the use of resources, and to measure the degree of shared responsibility (leading to social cohesion) expressed, MADIT (Methodology for the Analysis of Computerised Text Data) has been adopted [9, 10]. MADIT allows to analyse human interactions and discourses expressed using Natural Language, thanks to the codification in specific "units" of the interactive-discursive modalities usable by community members to produce a reality of sense: the Discursive Repertories (DRs). The DRs refer to the processual dimension of sense-generation, rather than the content used, and are collected in the Periodic and Semi-radial Table [10]. They are divided into three typologies, related to their "weight" (Dialogic Weight), i.e. the contribution to generating a higher or lower degree of shared responsibility.

MADIT allows to delve into the value attributed to both material (such as goods, natural resources, etc.) and immaterial (such as services) resources, i.e. which DRs are employed by citizens in using these contents. The sustainable consumption index, based on these assumptions, was used to measure how citizens' interactive-discursive modalities either promote social cohesion and shared responsibility or lead to social fragmentation and deresponsibility. The designed tool is structured in the form of a questionnaire with 2 open-ended questions and 8 multiple-choice questions (in which each response option corresponds to one or more DRs), with the aim of collecting textual data from participants. MADIT methodology allows to obtain an overall measure of shared responsibility on a scale of 0.1-0.9 Dialogic Weight. The lower the numeric index obtained, the more citizens assume the role of stakeholders, leading to social fragmentation; the higher the measure, the more citizens position themselves as community holders, promoting social cohesion.

Findings

The aim of the research was to highlight the value attributed to "sustainable consumption" configuration (i.e. interactive-discursive modalities related to resource use) through the tool of the sustainable consumption index and the *ad hoc* designed survey, administered to Veneto citizens for a total of 279 respondents. The questionnaire was administered online, disseminated with the collaboration of local companies, associations, social movements and organizations.

The results presented here refer to the first open-ended question, which investigates the resource use choice configuration. The textual data collected were analysed through MADIT, obtaining 386 DRs. The analysis conducted showed a degree of sustainable consumption, in terms of shared responsibility, of 0.39 Dialogic Weight on a scale of 0.1-0.9 (Fig. 1). This score is below the median value of 0.5. Specifically, the main interactive-discursive modalities used by respondents are characterised by self-reference and a poor degree of shared responsibility (63.47% of DRs, red dots in Fig.1), followed by a high shared responsibility level DRs typology (20.98%, green stripes in Fig. 1), that ensures that the overall degree does not closely approach the minimum value of the continuum. Lastly, the least used DRs typology promotes a medium shared responsibility level (15.54%, yellow crossed lines in Fig. 1).

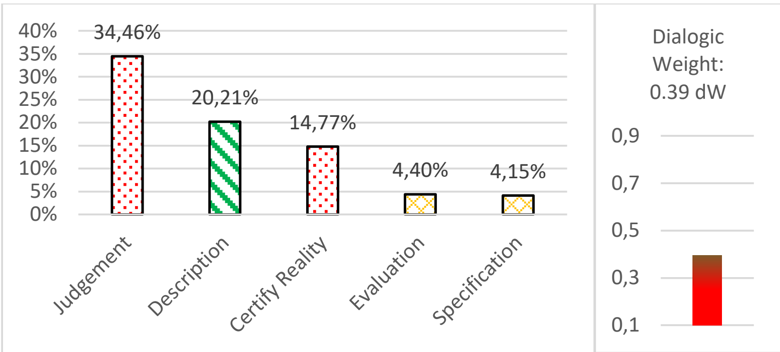

Figure 1. % of DRs most used by respondents to configure their resource use choice and related Sustainable Consumption Index

Discussion/Conclusion

Based on the medium-low level of the index, the tool highlights that the competence of describing the choice of resources use expressed is a critical aspect for shared responsibility and, therefore, social cohesion of the community. This measure shows how Veneto's citizens mostly interact through self-referential criteria in their resource use and contribute minimally to the shareability within the community (i.e. stakeholder position). The main DRs used underline that Veneto citizens mostly attribute value to resource use choices from unique positions, establishing a "state of affairs" through the conveyed content, oriented to the satisfaction of personal interests.

The community arrangement studied is therefore primarily marked by a fixed, unmodifiable resource consumption by citizens. Indeed, the target community tends not to define its resource use in a co-responsible, explicit, and shareable way, implying that citizens do not align towards a common horizon for resource use. Instead, they operate on distant, personal "interactive fronts", consuming resources without considering their potential common value. Based on this, it is anticipable that less citizens share the value attribute to resource use choices, less they can generate common anticipations of the impact of using resources in a specific way, due to the lack of a shared reference as a "starting point". Also, it implies that personal interests can clash with community interests due to differently attributing value to resource use, leading to severe consequences like their potential depletion up to our species extinction (in a possible, albeit not yet near, future). Practical implications anticipated may include social fragmentation and opposition to laws aligning with international standards [1,2]. These could be seen as top-down impositions not catering to individual consumption interests, and lacking a clear and shared "vision" of their foundation and objectives.

This study's limitations include its broad investigation focus on citizenship. To enhance the precision of the tool, a version targeting and distinguishing between specific roles within the territory (such as political, corporate or organizational) could be developed. This would allow observing these actors' interactive-discursive modalities, providing a more detailed 'snapshot' of the community arrangement.

In conclusion, through the innovative approach adopted, a sustainability consumption measurement index applicable to different contexts has been designed, which generates a 'snapshot' of community resource use modalities, thus providing a significant contribution to this field. In fact, this sustainable consumption index allows to measure the degree of shared responsibility of citizens in resource management, highlighting the contribution offered for the social cohesion of the territory and, therefore, for the conservation of the species. As for the future developments of what has been described, we aim to further refine the index to enhance the specificity of its descriptive capabilities. For example, by theoretically defining further intervals, between the two poles of the continuum, that represent a more detailed shared responsibility configuration of resources use choices.

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Green taxation: an Italian and European perspective

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Abstract

Green taxation is not a new topic in Italian and EU law, as demonstrated by the numerous legislative and doctrinaire contributions on the subject, but it is a topic of fundamental interest today because of the implications its use has on environmental protection and conservation choices. The aim of this contribution is to reconstruct the legal framework that environmental taxes have in the Italian legal framework and in the law of other EU Member States. We'll define what green taxes are and observe how different forms of green taxation are adopted at a wider or narrower legislative level. This contribution presents which green taxes are currently adopted in the Italian legal framework, briefly introducing the role of green taxes in other European Countries[1].

Keywords: *Green tax; Environmental taxation; Carbon Tax; Plastic tax; Waste tax.*

Introduction

The term 'green tax' refers to a broad group of fiscal tools that aim to promote both a political economic scope and an environmental one. The translation of the term may assume different meaning depending on the legislative definition of the taxation tools provided for by the laws of each state. As the Regulation (EU) n. 691/2011 states, "'environmentally related tax' means a tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment, and which is identified in ESA 95 as a tax". The relevance of these fiscal tools is still fundamental in 2024, even though green taxation exists since the '70s and have widely been used in many EU States in the '90s [1], because of the current environmental crisis, as green taxation covers a wide number of environmental concerns. In fact, the green taxes vary from country to country, but are mostly directed to reduce either the greenhouse gases (GHG) emissions addressing the energy consumption, the plastic pollution derived from single use plastic, or the impact of the waste management.

[1] Please note, this work is the summary of the author's Master degree thesis: for reasons of *brevitas*, some more detailed information about the green tax in Member States (including Italy), about certain green taxes and about the double dividend hypotesis had to be left out, but will be eagerly provided to anyone who'll ask for them.

Green taxes can be divided into categories based either on the premise they have an impact on or on the economic effect they produce [1,2]. Based on the premise they affect; it is possible to distinguish:

- emission taxes, related to the dispersion of pollutants or noise emissions. These taxes consider the quantity and quality of the pollutant and the costs of the damage caused to the environment;
- taxes on resource exploitation, the purpose of which is to cover the costs of treatment, collection and disposal and the administrative costs of the resource's managment;
- levies on the production or consumption of products that are harmful to the environment (whether when used by individuals or in industrial processes).

Based on the economic effect that they produce, green taxes can be divided as the European Environmental Agency and the OECD classified them:

- cost-covering charges: these are the type of environmental taxes that were first formed from a traditional model of implementing environmental regulatory policies. These taxes are based on the Polluter Pays Principle;
- incentive taxes: whose purpose is to induce a change in every behavior that harms the environment, without the revenue obtained from the tax itself being a primary objective. The value of the fee will be defined on the basis of an estimate of the cost of the damage or price signal needed to achieve the environmental objective that the levy promotes. Revenues are typically used to further encourage changes in polluting behavior;
- fiscal environmental taxes: are aimed at changing environmentally damaging behavior, but whose revenues nonetheless take on greater significance than those simply related to environmental regulation. Revenues obtained from these taxes can be used as part of broader environmental taxation, either to offset budget deficits or to shift the tax burden from another premise to the environmental premise being taxed.
- Environmental taxes fall, in the legal framework, under the competence of both the European Union, national legislator and local authorities. In order to identify the competence in relation to environmental taxes, it is first necessary to refer to what is the peculiarity of this instrument, namely, the dual membership in the sphere of fiscal and environmental matters. In the Italian legal framework, the taxation against GHG is within the competence of the EU, while other green taxes such as the plastic tax and the waste tax are respectively competence of the national legislator and of the regional or municipal authorities.

Methods

Green taxes in Italy

The Italian Plastic Tax has been introduced with the 2020 Budget Law (Law No. 160 of Dec. 27, 2019, Article 1, paragraphs 634-652), and is supposed to become effective in 2025. It is a tax on the "MACSI," an acronym that stands for single-use products, and targets single-use plastic pakaging, that "have or are intended to have the function of containment, protection, handling or delivery of goods or foodstuffs". Composable MACSI or single-use medical devices are excluded from the tax. Devices that enable the closure, marketing or presentation of other MACSI or artifacts consisting of materials other than plastics and semi-finished products, used in the production of MACSI are considered MACSI. The tax obligation arises at the time of production or final importation into the national territory and becomes payable upon release for consumption of the MACSI. The Plastic Tax on MACSI is intended for taxpayers who assume an entrepreneurial status: the rule indicates as liable to pay the producer, those who purchase them in the exercise of an economic activity and those who import them, not the final consumer (although, evidently, since the tax is a cost for the entrepreneur, this cost will be reflected in the final price paid by the consumer). We cannot ignore, however, the very small scope of the tax, which will only marginally affect the price of products contained in MACSI, which is why it is reasonable to expect that the levy will not have a significant impact on reducing single-use plastic consumption due to the economic deterrent factor alone. We can hope that, together with other instruments and policy choices made both at the national and European level, the tax can act as a deterrent by raising awareness of the problem that single-use plastic represents for our planet.

Waste disposal and management taxes are under the local authorities' competence and cover the costs related to the collection and disposal of waste. Among waste taxes we can distinguish TARI, introduced by the 2014 Stability Law, which serves to cover the costs of disposal and collection of municipal solid waste ("TARI" is the acronym for the Italian translation of "tax on waste"). It is a tax with respect to which some perplexities have arisen, especially regarding the presupposition on which it is based: despite the regulatory provisions, the system through which to weigh the waste has never been implemented, as envisaged back in the late 1990s (for the tax that was then called TIA). The presumption is therefore determined by the ownership or possession of a property in the municipality and the basis of calculation for TARI is established through statistical data, with reference to the size of the property, indicative of a presumption to produce waste. Some municipalities are choosing to apply the criteria of the effective production of waste with the TARIP (the "Precise TARI") instead of the TARI. The TARI can certainly be classified as a cost-covering tax. There is also the Provincial Tribute for the exercise of the functions of environmental protection, preservation and hygiene (TEFA), established by

Legislative Decree 504/199, which covers the administrative expenses related to the management of the taxes, and can be considered an additional to TARI.

It is also worth mentioning the special landfill tax for solid waste, established by Law No. 549/1995, payable by the operator of the storage company (but with the obligation of recourse) for the landfilling of solid waste. The marked environmental purpose of the tax is also evident from the fact that it is referred to as an "eco-tax". The tax base is determined by the amount of waste disposed of, recorded in the special records for reporting managed by landfill managers, adjusted by a correction coefficient to reflect the external cost caused by disposal. The objective of the ecotax is to promote waste and energy compsumption reduction, thus taking on the connotation of an incentive tax. The revenue from the tax, moreover, is partially tied up (and in this a function of an environmental tax budget is recognized) to a regional fund for the reduction of the amount of waste produced [4,5].

The EU's Carbon Tax

The Carbon Tax, even if it has been part of many Member States' legislative projects autonomously, has seen its peak of success with the European Union's legislation. Firstly implemented with the Directive 2003/87/CE, the European Carbon Tax was part of the Emissions Trading System (ETS) [3]. The Carbon Tax is now part of the European Green Deal and of the Fit for 55% reforms, with its wider and more complex structure as the Carbon Border Adjustment Mechanism (CBAM). The CBAM is an environmental tax established by the European Union through Regulation 2023/956 to counteract so-called environmental dumping, or carbon leakage, i.e. the use of highly polluting production processes that do not comply with the sustainability goals of the 2015 Paris Climate Agreement, but can still be used in some countries outside the EU. The CBAM subjects goods from third countries to a tax based on their carbon emissions, similarly to the tax imposed on European goods by the ETS.

The main objective of the CBAM is to counteract the importation into the member states of products from foreign suppliers that adopt polluting production processes, while also eliminating the advantage within the European market that products from countries with less stringent legislation, such as China and India, have, by virtue of the less stringent standard of environmental protection provided by these jurisdictions. In addition to its environmental purpose, the tax should also incentivize the reshoring of productions that were relocated to avoid the environmental standards.

The tax does not apply to all products, but is limited to specific categories, including cement, fertilizer, iron, steel, hydrogen, aluminium, and electricity. The introduction of the CBAM will be phased in gradually, with a transition period from October 1, 2023, to December 31, 2025, a period during which importers will have to report the amount of carbon emissions from imported goods. The tax will then become fully operational in 2026.

Conclusion

Green taxes are characterized by a fragmentation within the multilevel legal framework that complements effectively in enhancing their strengths. In fact, environmental taxes under the jurisdiction of local governments are the most effective in fulfilling their function, intervening in a circumscribed territorial scope, for the management and maintenance of artistic and cultural heritage and for the management and disposal of waste. The efficiency and functionality of these taxes, however, do not call into question the need to have green taxes of national or supranational relevance, but, rather, are a valid explication of the importance of implementing the multilevel legislative structure in green taxation. One can therefore appreciate the importance of supranational management of the carbon tax and hope that, in matters that so significantly affect the entire planet, the integration of environmental taxation among member states will continue (and spread to non-EU countries as well).

A further element of richness in the environmental tax system can be appreciated with reference to the member states' green taxes. While on the taxation of carbon dioxide emissions in production processes the European institutions have elaborated, with ETS and CBAM, a shared tool, in the other areas the states have moved autonomously and recognized the importance of taxing different sectors that in different ways pollute the environment. The choice of a plastic tax as a response to the European policy choice, defined in Directive 2019/904/EU, to take action on the reduction of plastic dispersed in the environment, has been shared by Spain, the Netherlands and Italy [6]. In France, the introduction of a tax on fast fashion is being discussed, the polluting impact of which spans a multitude of aspects: soil and water pollution from the use of pesticides in cotton cultivation, textile industry discharges and the dispersion of microplastics in washing, and the emission of GHG that contribute to global warming [7]. Looking just outside the Union's borders, Norway has begun to talk about meat taxation, recognizing the importance of livestock farming in the production of GHG (an issue that, moreover, the CAP 2023-2027, has also emphasized). Among the member states, the issue of applying the double dividend hypotesis theory to environmental tax reforms has also emerged: the idea of shifting the weight of the tax burden from labor to environmental taxation has taken hold especially in Denmark, Sweden, Finland, Norway and Germany [8].

The environmental tax system is, in the EU, certainly still evolving, and it will be interesting to observe which taxes will take hold and whether they will be integrated at a supranational level. However, the protection of the environment in all its facets remains a problem with a global dimension, for which the European response is not sufficient. In this sense, one can appreciate the direction dictated by the CBAM in preventing the risk of carbon leakage.

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AGRI FOOD SECTOR

Analysis of possible scenarios for the valorization of waste from the Marche's construction and agribusiness sectors

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Abstract

The current production system operates on a linear process: raw materials are used to create products, generating waste. This has led to overexploitation of the planet's resources and waste disposal issues. The system is in crisis, and neither the economic situation nor the climate emergency is helpful. Industrial symbiosis emerges as a solution to reduce emissions and achieve a sustainable economy. Its success requires propitious conditions to create an interconnected network of companies. The paper initially discusses industrial symbiosis practices with examples, then focuses on analysing the business landscape to highlight favourable situations. Conducted during an internship at ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, for the Marlic project in the Marche region, the study aims to offer replicable solutions elsewhere, demonstrating the methodology's effectiveness.

Keywords: *Circular economy; Industrial symbiosis; Waste; Recycling.*

Introduction

Today's production system is in crisis, and highlighting this are the difficulties in sourcing materials, scarcity of resources, and saturation of waste disposal capacity, which inevitably limit the economic growth of many businesses. The linear model is not sustainable economically, let alone environmentally. The circular economy is the most sensible alternative if economic development is to be achieved while respecting the environment and its resources.[1] In this context, Industrial Symbiosis manages to emphasise a systems-oriented approach. It suggests that industrial systems should not be developed in isolation; rather, they need to be considered in connection with all surrounding systems and the broader environment.[2] The work was carried out during the internship activity at ENEA, as part of the Marlic project, funded by the Marche regional program, which aims to set up a regional collaborative research laboratory in areas affected by the earthquake on the issues of eco-sustainability of products and processes for new materials and on de-manufacturing. For this purpose, a preliminary analysis was carried out on some sectors of interest in the business fabric of the Marche region to derive hypothetical scenarios of waste valorisation from a circular perspective.

Methods

The methodology used for the analysis involved definite steps. In the initial phase, there was the identification of the sectors of interest for the study, based on an assessment of economic and environmental indices, and the subsequent identification of the relevant entrepreneurial realities in the Marche region through AIDA databases, using the ATECO 2007 commodity classification. Next, a characterization of the entrepreneurial fabric, exploiting Istat, Ecocerved and Chamber of Commerce data. Then, the focus shifted to the economic context in which the identified companies fit and then to the identification of input and output resource flows that characterize the supply chain and related production processes. Finally, a literature search was carried out to identify the technologies and methods of valorisation of the by-products coming out of the processes and, therefore, possible scenarios of industrial symbiosis hypothesized for the companies in the Marche region, but also replicable in contexts and places other than the latter.

Findings

The methodology applied to the sectors of interest returned potential collaborations for companies in the Marche region, expressed by synergistic layouts showing the resource flows and ATECO codes of the companies involved.

Construction & Demolition Sector

The first of the two sectors analysed was Construction and Demolition, identified by ATECO 2007 codes F: 41, 42, 43. The choice was mainly due to the quantities of special waste produced by the said sector (about 3 percent of the total for the Marche region) and the disposal problems arising from it [3][4][5]. The analysis of resource flows in input and output to the production process suggested a valorisation scenario involving the reintroduction of by-products and waste within the same cycle, after appropriate reprocessing entrusted to intermediate companies. In Figure 1 the synergistic layout expressing the potential collaboration identified.

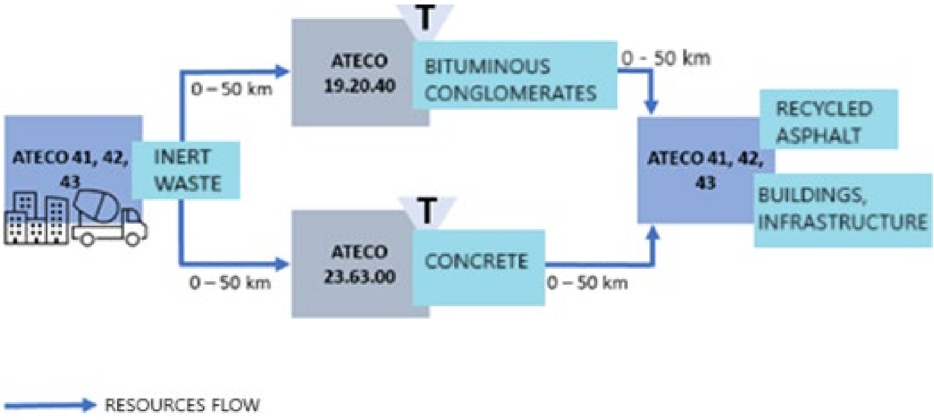

Figure 1. Construction & Demolition sector resources flow

Agri-food sector

The second sector taken into analysis is the agri-food sector, which encompasses both the primary sector (ATECO code A) and the food and beverage industry (ATECO C: 10 and 11). Already by themselves, the Marche region's enterprises carrying out primary activities in the territory account for 16.9 percent of the total, it is a sector with high economic significance and capable of involving numerous business entities.[6] Again, input and output resource flows were studied, possible synergistic collaborations identified, and symbiotic clusters hypothesized in the Marche region. In detail, only the wine (Figure 2), olive oil (Figure 3), meat (Figure 4a and 4b) and fishing (Figure 5) industries were considered, as they are more widespread in the territory.

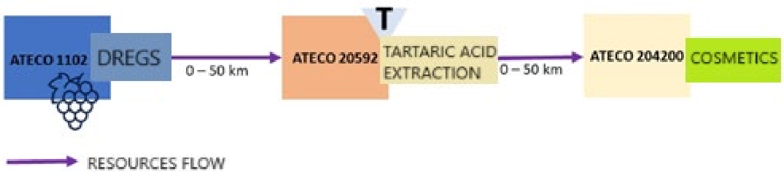

Figure 2. Wine industry

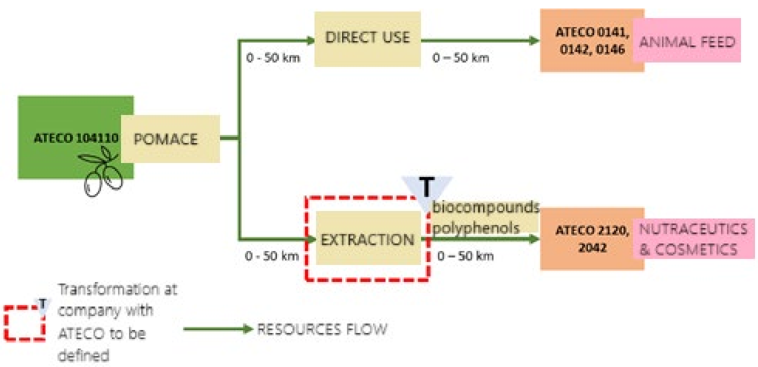

Figure 3. Olive Oil industry

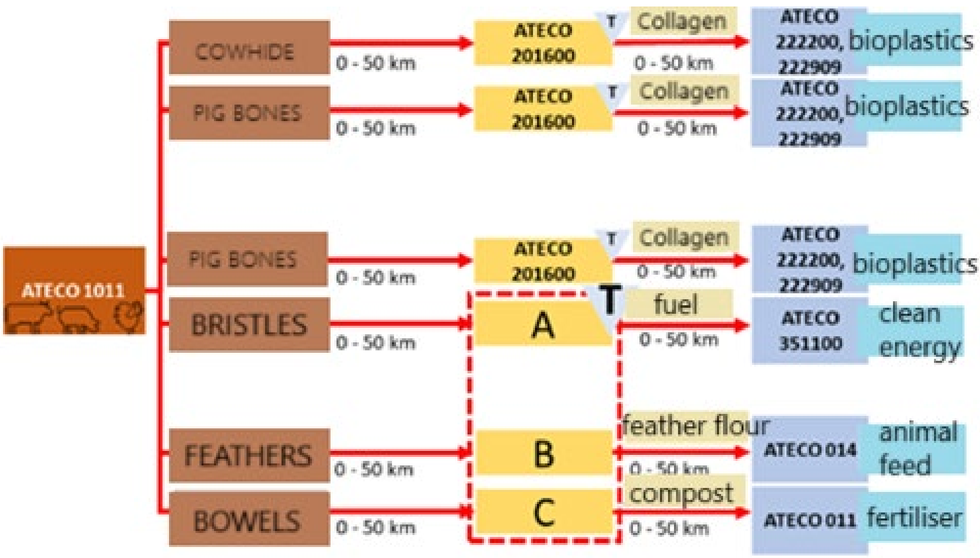

Figure 4a. Meat industry (Cows and pigs)

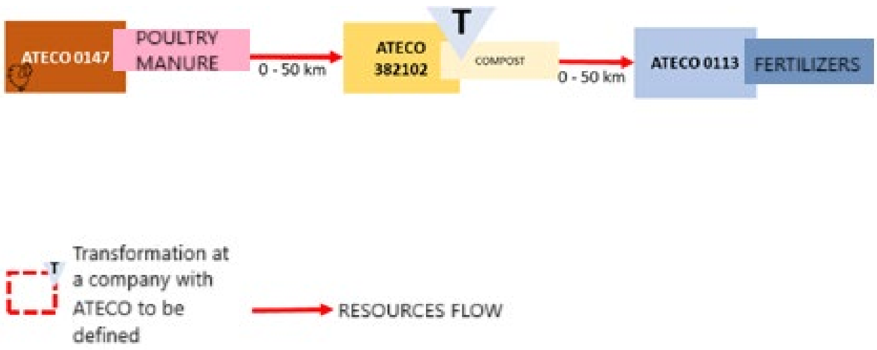

Figure 4b. Meat industry (poultry)

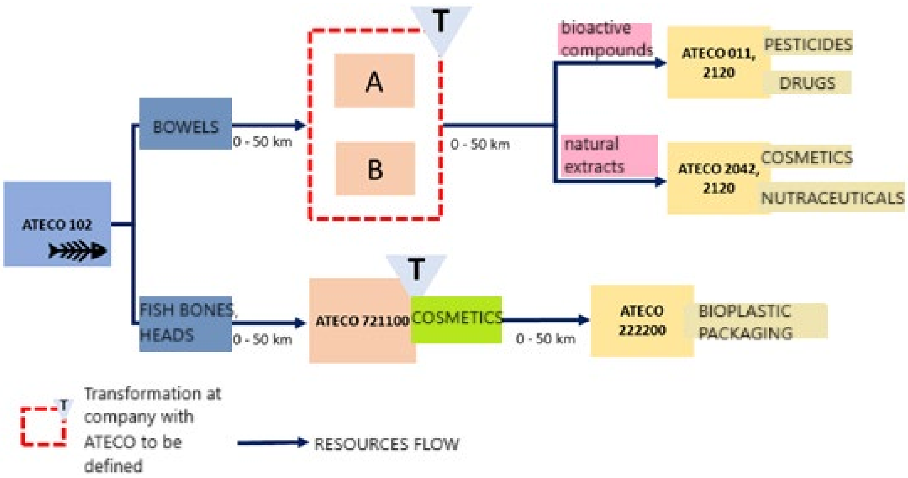

Figure 5. Fish industry

Discussion/Conclusion

The analysis showed that there are possible matches between companies that can valorise by-products and move to a circular production model. However, symbiotic compatibility alone is not enough for the implementation of an Industrial Symbiosis network. First, it is necessary to assess the resulting economic convenience for the companies participating in it;[7] in this paper, a maximum distance constraint of 50km was imposed for symbiotic clusters to ensure at least plausible convenience with regard to the logistics factor. Another aspect that needs to be taken into consideration is the current regulations regarding the reuse of by-products and, in general, this type of synergy between companies. Added to this is the need to build trust among project stakeholders and to raise awareness of the issue among all possible participants in the symbiosis network.

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A transcriptomic approach to a complex system for the control of post-harvest disease with sustainable products

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Abstract

This study explored the use of a minimally processed shrimp waste to control fungal and oomycete pathogens in citrus plants to reduce environmental pollution and health risks from pesticides. The efficacy of the extract was tested in vitro by agar diffusion, MIC, and MFC evaluation, and in vivo on orange and lemon fruit infected with Penicillium digitatum. In vitro tests showed significant inhibition of pathogen growth, with MIC and MFC values ranging from 2 to 3.5%. In vivo tests confirmed the extract's ability to prevent post-harvest citrus rots and enhance the expression of plant resistance genes, proposing it as an environmentally friendly solution for plant pathogen management.

Keywords: *Citrus fruit; Post-harvest diseases; MIC; MFC; Gene expression.*

Introduction

Fast Plant pathogens cause serious diseases that affect agricultural production, compromising food safety through quantitative and qualitative yield reductions. Pesticides have adverse effects on human, non-target species, biodiversity, and aquatic and terrestrial ecosystems. There has been growing interest in environmental and economic sustainability, promoting the development of "green technologies" and the use of "green products". Concepts, such as the circular economy, have emerged with the aim of minimizing waste [1]. Scientific research increasingly focuses on valorizing industrial waste, particularly from processing industries [2]. From an ecological perspective, products derived from processed waste could represent a valuable economic resource. Extracts from shrimp waste have shown a potential in pathogen control against various human pathogens and food contaminants, such as *Escherichia coli*, *Shigella flexneri*, *Bacillus subtilis*, *Salmonella typhi*, *Enterococcus faecalis*, and *Proteus vulgaris* [3]. Extracts are rich in beneficial bioactive compounds and find applications in different fields [4,5]. Shrimp waste is a plentiful source of carbon, nitrogen, oxygen, and active compounds suitable for biotechnological applications, such as wastewater treatment [5]. The study aimed to evaluate the ability of a new extract from a minimal processing of shrimp wastes *1.* to control *in vitro* and *in vivo* fungal and oomycete pathogens of genera *Alternaria, Colletotrichum, Fusarium, Penicillium,* *Plenodomus*, and *Phytophthora; 2. to* modulate the plant defense response in orange and lemon fruit.

Methods

Shrimp extract, fungal and oomycete pathogens

Shrimp waste from the species *Parapenaeus longirostris,* purchased at a fish market in Catania, was transported processed to obtain a shrimp extract as described in El boumlasy et al. 2021 [7]. The strains used in this study were from the Molecular Plant Pathology Laboratory collection at Di3A (University of Catania, Italy).

Evaluating *in vitro* inhibitory activity of the shrimp extract by agar diffusion test

The inhibitory effect of shrimp extract on fungal and oomycete pathogens, using an agar diffusion test, were done in accordance with El boumlasy et al. [7]. Each pathogen was tested on a Potato Dextrose Agar (PDA) plate by spreading 500 µL of conidial/zoospore suspension at the concentration 10^6 spore/mL. Five wells were made on the PDA plate, and 60.0 µL of the extract, at different concentration, were dispensed into each well. Plates were then incubated at 25°C for three days.

Minimum inhibitory concentration (MIC) and minimum fungicidal concentration (MFC) of shrimp extract

Minimum inhibitory/fungicidal concentrations of shrimp extract for each pathogen were determined by *in vitro* tests. For MIC determination, 400 µL of shrimp extract at specific concentrations, 400 µL of sterile PDB, and 200 µL of spore suspension were added into 2.0 mL tubes to obtain 10 serial dilutions (1 mL each) of the substance. Tubes were incubated at 25°C for 3 days. MIC was the lowest concentration without turbidity, indicating the absence of pathogen growth. MFC was determined by transferring 10 µL from each well without turbidity on PDA plates, which were incubated at 25°C for 3 days. MFC was the concentration with no mycelial growth.

Evaluating *in vivo* antifungal activity of the shrimp extract

The antifungal activity of the shrimp extract was evaluated *in vivo* on orange (*Citrus* × *sinensis* cv. Valencia) and lemon (*Citrus* × *limon* cv. Femminello Siracusano) fruit artificially infected with *Penicillium digitatum* strain P1PP0, the causative agent of the post-harvest disease 'citrus green mold'. Fruits, sterilized and wounded at four points, were inoculated with *P. digitatum* and left to incubate at 20°C and 80% humidity for 24 hours [7]. Different concentrations of shrimp extract (*i.e.,* shrimp extract such as, 75%, 50%, and 25% diluted in sterile distilled water) were applied to the wounds (treatments ID02, ID04, ID06, and ID08 respectively). Control treatments were fruits treated with sdw (ID01) or different concentrations of the solvent used to prepare the shrimp extract: $NaNO_3$ at 0.17 g/mL (tr. ID03), diluted in sdw at 75% (tr. ID05), at 50% (tr. ID07), and at 25% (tr. ID09). Three fruits were used per treatment. The shrimp extract ability in controlling the citrus green mold was recorded at 3 and 5 days after inoculation and expressed as rot severity, rated according to empirical scales, from 1 to 5 as follows: 1. absence of symptoms or signs; 2. slight presence of rot; 3. clear presence of rot and slight appearance of mycelium; 4. rot and clear presence of white mycelium; 5. clear presence of soft rot, white mycelium and sporulation.

Evaluation of shrimp extract effectiveness in eliciting plant defense response in citrus

To evaluate the extract's effect on plant defense, three genes central to the plant's natural response were analyzed: β-1,3-glucanase, phenylalanine ammonia-lyase (PAL), and peroxidase (PEROX) were analyzed. A test was done on orange and lemon fruits treated as follows: i. water (control); ii. K-Phi (reference commercial plant-biostimulant - control); iii. solvent used to obtain the shrimp extract (control); iv. shrimp extract as such. Each fruit, wounded at eight points, was treated with 10 µL of the respective substance. Fruit peels from each treatment were collected at 0-, 24- and 48-hours post-treatment frozen in liquid nitrogen and stored at -80°C for gene expression analysis. RNA extraction and quantitative analysis of gene expression were performed in accordance with previous studies [7,9].

Findings

Agar diffusion tests

In agar diffusion test, various concentrations of shrimp extract showed inhibitory effects on different fungal and oomycete pathogens. The diameters of inhibition zones were directly correlated with extract concentration. The highest inhibition was observed against *Plenodomus tracheiphilus* isolate Pt2, *Phytophthora nicotianae* isolate T2. C-M1A, *Fusarium sacchari* isolate CBS 145949, *Alternaria alternata* isolate 646, and *P. digitatum* isolate P1PP0. All post-harvest pathogens were affected, and significant variations in inhibitory effects were observed among different fungal and oomycete species, even within the same genus and among different strains of the same species.

Evaluation of MIC and MFC

The results of MIC and MFC evidenced values of both parameters ranging from 2% to 3.5% for all pathogens. The highest MIC values (3.5%) were recorded for *Penicillium expansum* isolate CECT 2278 and *F. saccari* isolate CBS 145949, while the lowest (2%) were recorded for *Colletotrichum gloeosporioides* isolate C2, *P. nicotianae* isolate T3-B-K1A, and *P. tracheiphilus* isolate Pt 2. MFC values were the same as the MIC for most strains. Only for *Penicillium commune* isolate CECT 20767, *A. alternata* isolate 646, *P. nicotianae* isolate T3-B-K1A, and *Phytophthora citrophthora* isolate Ax1Ar, the MFC was higher than the MIC, indicating that the MIC had only a fungistatic effect for these four strains.

Evaluation of *in vivo* antifungal activity

Three days after inoculation with *P. digitatum* P1PP0 on orange fruit, all concentrations of the extract significantly reduced the severity of rot caused by the pathogen compared to the water control, particularly in fruit treated with the shrimp extract as such (ID02) and at 25% (ID08) (Figure 1a). Five days after inoculation, all concentrations of the extract determined significantly lower rot severity values compared to the water control (ID01). However, at this stage, only the treatment at 25% (ID08) determined a significant difference from its control (ID09) (Figure 1b). For lemon fruit, three days post inoculation all tested concentrations of shrimp extract significantly reduced the severity of rot compared to the controls, especially in fruit treated with the shrimp extract as such (ID02) and in those treated with the extract diluted at 75% (ID04) (Figure 2a). Furthermore, fruits from these two treatments were the only that maintained significant efficacy in reducing rot severity in lemons five days after inoculation (Figure 2b).

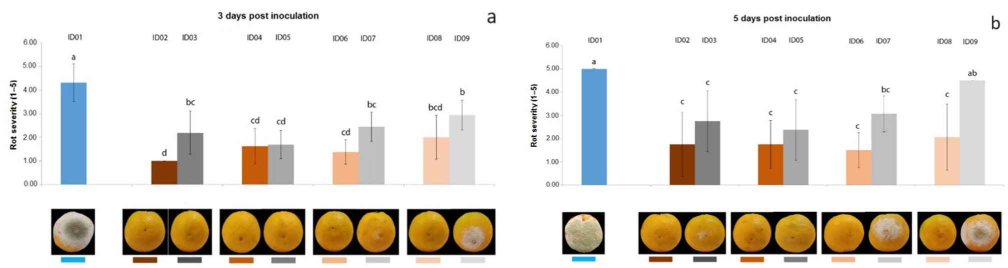

Figure 1. Rot severity caused by *Penicillium digitatum* strain P1PP0 in orange (*Citrus × sinensis*) fruit cv. Valencia treated with water (ID01) or shrimp-extract as such (ID02), 75% shrimp-extract (ID04), 50% shrimp-extract (ID06), 25% shrimp-extract (ID08) and respective controls (NaNO3 0.17 g/mL—ID03; NaNO3 0.17 g/mL diluted in sterile distilled water (sdw) at 75%—ID05; NaNO3 0.17 g/mL diluted in sdw at 50%—ID07; NaNO3 0.17 g/mL diluted in sdw at 25%—ID09) 3 and 5 days after inoculation.

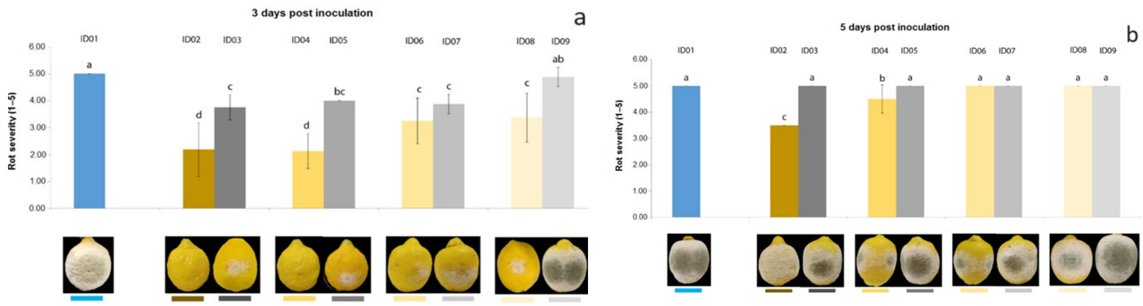

Figure 2. Rot severity caused by *Penicillium digitatum* strain P1PP0 in lemon (*Citrus × limon*) fruits cv. Femminello Siracusano subjected to the same treatments of Figure 1, 3 and 5 days after inoculation.

Evaluation of differences in gene expression related to induced resistance in citrus

Results of gene expression in fruit treated with the shrimp extract indicated that at 0 hours post-treatment, orange fruits had a marked upregulation of β-1,3-glucanase, PAL, and PEROX genes, indicating the activation of these genes-related defense mechanisms. This upregulation decreased at 24- and 48-hours post treatment. In lemon fruit, treatment with shrimp extract strongly elicited the transcription of the gene encoding for β-1,3-glucanase. Fruit from this treatment had a marked upregulation of PAL at 24 and 48 hours, as well as a notable upregulation of PEROX after 24 hours.

Discussion/Conclusion

This study evaluated for the first time the potential of an extract derived from minimally processed shrimp waste in the *in vitro* control of fungal and oomycete pathogens of *Alternaria, Colletotrichum, Fusarium*, *Penicillium, Plenodomus,* and *Phytophthora*, and in the *in vivo* control of citrus green mold caused by *P. digitatum*. The extract also modulated the expression of plant-defense genes β-1,3-glucanase, PAL, and PEROX in citrus peels. *In vitro* tests showed the extract effectively inhibited several pathogens, including *P. tracheiphilus*, the causative agent of citrus mal secco [9]. *In vivo* tests demonstrated a significant reduction in rot severity and upregulation of defense genes. Further research is needed to evaluate the extract's phytotoxicity, systemic translocation, and application methods. In conclusion, based on the results obtained from this research and many others, the importance of the circular economy in the current landscape appears crucial. To reduce environmental pollution and its effects on human health, this study envisions adopting of low-impact technologies and products. Specifically, it advocates for the reuse of waste materials, such as shrimp extracts, by employing them as low-impact fungicides, thereby supporting sustainable practices. The circular economy thus represents a fundamental approach to driving ecological innovation and guiding society toward a "zero waste" model. Statistical data from research conducted in Europe on consumption habits reveal that a significant portion of resources is wasted, and waste is generated not only from what we consume but also from the inefficient way we use these resources [9]. Therefore, the circular economy focuses primarily on eliminating wasted opportunities and addressing the issue of inefficient utilization. It is not merely about "doing more with less" but rather "doing more with what we already have" through reduction, reuse, recycling, and recovery [10], following a sustainable and efficient approach. In this context, products derived from waste processing, such as those from shrimp, can represent a significant economic resource, contributing to the promotion of sustainable practices and the reduction of waste.

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Extraction and characterization of humus like substances from an anaerobic digestate of zootechnical waste

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Abstract

In recent years the increase in the production of livestock waste has prevented it from being fully utilized on agricultural land, constituting an expense for farmers due to the massive storage of the liquid fraction. The aim of this study is the determination of humic-like substances contained in a biosolid obtained from the suspended solid fraction of a biodigestate of zootechnical waste in order to evaluate possible applications in agriculture. The biosolid (BZ) was compared to other soil improver materials such as peat (TS), mixed compost amendment (AC), leonardite (LC) and coffee residues (RC). The material analyses determined the loss of ignition, the organic carbon and its fractionation as well as humification parameters. The results show that the biosolid contains significant amounts of substances whose properties overlap more with humic acids and to a lesser extent with fulvic acids.

Keywords: *Humic acid; Livestock wastewater; amendment.*

Introduction

In recent years, the rise in the demand for animal products has resulted in an increase in the number of farms and animals. This has led to a growing production of zootechnical waste. The primary method for the recovery of these wastes involves their use in agricultural land for fertilizer purposes, owing to its nutrient content. Due to this phenomenon the quantities of livestock manure produced exceed the limits for application to the soil, resulting in an excess of nitrogen-rich material. To prevent the pollution of surface waters with nitrates, it is necessary to manage the application of livestock manure properly due to these levels, a problem that is shared with sewage sludge [1]. Material and energy recovery actions can be used to partially manage these excesses. The biogasification process, enables the production of biogas and biodigestate from biomass. Upon completion of these processes, the solid component can be retrieved, stabilized, and utilized as fertilizer [2]. The main issue concerns the liquid fraction which has high management costs and preserves nitrogen levels. The hypothesis of this study is that, as a result of the biodigestion process, humic biosolids are produced and concentrated in the liquid fraction. If effectively separated and enhanced, this material could potentially play a role in reducing the expenses of treatment/disposal of residual zootechnical waste. Humic substance represents a component of soil organic matter (SOM), including both humic acids (HA) and fulvic acids (FA), which are complex macromolecules present in soils, sediments, and water sources. As constituents of SOM, their composition is influenced by factors that impact degradation processes, resulting in significant variations in the composition of HA and FA depending on the original source material. Despite these differences, humic acids share key macro-characteristics with the molecules that constitute this group: notably they possess a high molecular weight (ranging from 20 to 1,300 kDa), the presence of carboxylic (-COOH) and phenolic (-OH) groups and exhibit insolubility at pH level ≤ 1 [3]. Humic acids possess an amphipathic nature, rendering them a feasible substitute for non-polar solvents in the elimination of pollutants from aquatic environments. They demonstrate strong compatibility with polycyclic aromatic hydrocarbons (PAHs) and other contaminants [4]. Research into the impact of applying humic substances on soils has been ongoing for an extended period, yielding favorable outcomes in both their fertilization capacity and their utility in rehabilitating degraded soils [5,6]. Additionally, the application of humic acids also extends to the medical field where, preliminary evidence suggests a potential interference with the replication of HIV types 1 and 2 within the host [7]. The aim of this study is to propose a possible incentive route through the economic valorization of the biosolid produced, proposing it as a possible new recovery soil improver rich in humic substances, in order to push producers towards the correct disposal of excess zootechnical waste, thus promoting the correct health of the soil system and the aquifer system.

Methods

Samples

Five organic materials were compared, categorized into plant matrices and materials from the recovery chain commonly utilized as soil enhancers. Two standard materials, from a non-renewable resources, traditionally used for the high content of humic substances: Peat (TS), sourced from fertilizers factory SCAM s.r.l. (Modena), represents a standard material, to be used in organic-based fertilizers; Leonardite (LC), sourced from fertilizers factory CIFO s.r.l. (Bologna) is a material of fossil origin akin to lignite, but distinguished by a higher degree of oxidation.

Three newly developed humus-like organic materials: the mixed compost (AC) soil enhancer comes from by-products biomethane production of factory of Consorzio Energie Alternative S.p.A. (CEA, Caivano, Naples). That material derives from the dry digestion process of organic waste fractionated from municipal waste (OFMSW) and it has used as a soil enhancer due to its elevated levels of humic substances. Coffee residue (RC) from Baritalia factory in Grumo Nevano (NA), derives from leftover coffee powder after brewing, contains polyphenolic substances precursors of humic acids; Biosolid (BZ) is acquired from the liquid portion of zootechnical waste digestate subjected to biogasification at the factory Powerinasce S.r.l. (Santa Maria la Fossa, Caserta). The material undergoing biogasification comprises a blend of livestock manure and plant materials abundant in starchy and cellulosic components, crucial for enhancing fermentation process. Once removed from the plant, it underwent autoclave treatment to reduce the bacterial presence. All samples were dried in an oven to eliminate excess moisture, followed by initial grinding and sieving to reduce the materials to a diameter below 0.2 mm.

Loss of ignition

Through the loss of ignition method, volatile substances in samples can be quantified. This involves, weighing the samples and transferring them in special crucibles. Subsequently, these crucibles are placed inside a preheated muffle set at 350°C, with the temperature gradually increasing to 600°C. Once this temperature is attained, the samples are left in in the muffle for a duration of 48 hours.

Determination of organic carbon

The determination of organic carbon content was conducted through the utilization of the Walkley-Black and Springer-Klee methodologies. The Walkley-Black method is based on the oxidation of organic carbon into carbon dioxide, achieved under standard conditions, by employing a chromium solution in the presence of sulfuric acid. Dilution with acid induces a rapid temperature increase, enhancing the reaction rate, which is then halted by water addition. The unreacted potassium dichromate is quantified through titration with an iron (II) sulfate heptahydrate solution [8]. The Springer-Klee method operates on similar principles as the Walkley-Black method, differing only in its more efficient reaction between dichromate and organic carbon, achieved by heating the solution to 160°C [9].

Organic carbon fractionation

By using two extractive solutions, sodium pyrophosphate ($Na_4P_2O_7$) and sodium hydroxide (NaOH), it is possible to separate the extracted total organic carbon (TEC) and humic from the organic matter. Acidification of the pyrophosphate solution containing TEC allows the precipitation of humic acids (HA), leaving fulvic acids (FA) and other SOM compounds, including carbohydrates and amino acids, suspended in the solution. To separate the fulvic acids from the non-humic substance, purification by solid phase adsorption chromatography on polyvinylpyrrolidone (PVP) resin is required, which is able to adsorb the fulvic acids by forming hydrogen bonds with the phenolic groups of the acids, which can be dissolved with a NaOH solution allowing the elution of the fulvic acids. This application therefore enables the determination of TEC, humic acids and fulvic acids [9].

Humification parameters

The Humification Index (HI) is a qualitative and dimensionless parameter, between 0 and 1, indicated by the ratio between the content of organic carbon from the non-humified organic matter (CNH) and the humic carbon (CH) from the sodium pyrophosphate extract [10]. The Degree of Humification (DH) results from the ratio of humic organic carbon (HAC+HFC) to the TEC present in the soil. It is a qualitative-quantitative parameter that ranges from 0 to 100 and provides information on the percentage content of humic substances in relation to the extractable fraction [11]. The Humification Rate (HR) is a quantitative percentage parameter, required to assess the degree of stabilization of the organic matter contained in organic fertilizers and soil improvers [11]. Total Humification Level (HU): This is a quantitative percentage parameter, indicated by the ratio between total carbon to carbon attributed to the humic, fulvic and insoluble humic fractions [12].

Findings

The fire leak led to the distinction of composite materials, such as peat and composted soil enhancers, from those of clearly vegetable origin, such as coffee residues. According to the Walkley-Black method, biosolids (177.45 g/kg) have the second lowest value after peat (121.33 g/kg). According to Springer-Klee's analysis, biosolids have a value of 335.67 g/kg and thus belong to the group of fossil materials with leonardite and peat. The fraction data for the biosolids show that the mean values determined for TEC, HAC and FAC are 93.03 g/kg, 48.30 g/kg and 5.08 g/kg, respectively. the analysis of the humification parameters, shows that the biosolids have high HI, DH and HU and a low HR. These values are therefore in line with the other soil enhancers.

Discussion/Conclusion

At the end of this study, it can be concluded that the biosolid obtained from the liquid fraction of biodigestate from livestock manure contains significant amounts of substances with humic properties. The majority of these substances have characteristics similar to humic acids and, to a lesser extent, fulvic acids. However, the amount of humic acid-like substances in the biosolid is lower than the amounts found in the fertilizers used for comparison. Accordingly, the amount of fulvic acid-like substances is higher. Based on the calculation of the humification indices, it can be confirmed that this is a material with a reasonable degree of stabilization, which is fully comparable to other products in the soil enhancer category.

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NOStraw – Exploiting agricultural waste from Parco Sud Milano for social redevelopment within Nosedo Off Campus

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Abstract
Aligning to the 2030 Agenda and particularly focusing on objectives 10 (Reduced Inequalities) and 12 (Responsible Consumption and Production), the NOStraw project wills to bridge the fields of materials development, design, and social support within a local micro-economy. This project exploited agricultural waste from the Parco Agricolo Sud Milano to develop a biocomposite material. Specifically, disused wheat straw was used to create a particleboard-like material (NewStraw), through the combination of pulverized straw, corn starch, citric acid, and glycerol. NewStraw, processed using traditional woodworking techniques, was integrated into local social support associations within the Corvetto district. This initiative aimed to provide job and learning opportunities, particularly for vulnerable groups. The material was applied to produce an educational toy designed for primary school children, to engage them in urban renewal projects and improving community involvement. This approach did not only promote biocomposites production and use; it also supported social inclusion and educational development within the local community.

Keywords: *Agricultural waste; Wheat straw; Biocomposite; Social upgrading; Educational toy.*

Introduction
In a special meeting on April 26, 2023, UN Secretary-General António Guterres warned that without immediate action, the 2030 Agenda might become merely an epitaph for missed global opportunities [1]. The 2030 Agenda, established in 2015, includes 17 Sustainable Development Goals (SDGs) and 169 sub-goals aimed at ensuring global environmental, social, and economic well-being [2]. Of great importance within SDG 12 is the introduction of new behaviors to prevent (or more consciously manage) waste generated during the agricultural harvesting phase. The agricultural production phase is estimated to be the most impactful in terms of waste generation compared to other supply chain steps [3]. Cereals are particularly significant, accounting for 35% of the carbon footprint and 24% of waste generation within the agricultural cultivation chain [4]. Specifically, wheat cultivations are reported to generate approximately 361 kgCO_2 per ton of product [5]. Furthermore, during the harvesting phase, around 529 million tons of wheat straw are produced for disposal worldwide [6]. In the delimited local area

of Parco Agricolo Sud Milano, a wide agricultural site at the borders of the city, an average production of 4 tons of wheat straw per cultivated hectare is estimated [7]. To manage and reshape this waste into a new precious resource, the development of biocomposites using agricultural by-products was explored. Within scientific literature, biocomposites can be divided into different categories, based on the origin of the matrix [8]. In this work, the ones having both matrix and reinforcement of natural origin were explored [9]. In particular, the focus shifted to the ones composed by a polymer-based matrix: the so-called polymeric matrix composites (PMCs) [10]. Among the different natural elements used for the matrix [11], vegetable starch was widely investigated in literature for its widespread availability and its gelatinization capability at 60-80 °C [12]. Being typically brittle, the mechanical properties of starch can be improved by properly introducing a plasticizer [13], such as glycerol or sorbitol [14,15]. Several studies already investigated the possibility of developing biocomposites using plasticized starch while including agricultural fibers as a reinforcement [16,17,18,19]. This work followed the development of a new biocomposite according to such studies to upcycle local wheat waste.

Another key objective of the 2030 Agenda is certainly SDG 10, aimed at reducing social inequalities [2]. This objective, in parallel with the challenges of sustainable transitions, expresses the need to combine growth and equity, complementary goals that highlight the need for commitments to reduce territorial gaps and widespread development. In Milan, the Corvetto district is a focal point for social regeneration projects, due to its geographical configuration in between the metropolitan area of Milan and a wide agricultural site. In this zone there is a strong educational disparity and a lack of social integration due to high emigration and immigration flows [20,21]. Among the various initiatives of social rearrangement there are those of the Off Campus Nosedo [22], a cell of the broader Polisocial program: an initiative promoted by Politecnico di Milano which aims to devolve academic knowledge for social engagement [23]. Within this framework, the proposed research aims to investigate the development of a new biocomposite using local wheat straw waste, non-hazardous substances and low-technology replicable production processes. To achieve this, not only a procedure to realize biocomposites, but also an educational toy was designed to re-interpret agricultural waste in new ways and closing micro-loop production. The conceived productive methods for local associations were intended to create new job opportunities in the Corvetto area. The target users for the presented educational project were elementary schools in the neighborhood, and its design was inspired by the Montessori method for education of children between ages 6 and 11 [24,25]. The product included elements to enhance children’s spatial cognition skills, such as orientation and perspective [26,27] and offered the opportunity to teach how to give back life to waste for the new generations.

Methods

Biocomposite (NewStraw) development

The agri-food waste used during the testing was wheat straw, supplied by Cascina Scanna (Milan, Italy), currently representing waste without disposal options. Other substances involved in the formulation included Carghill (Minnesota, US) iCoat corn starch, Nortembio (Cadiz, Spain) citric acid, and pure glycerol from Marco Viti S.p.A. (Como, Italy).

First, the straw was pretreated by soaking in water for 30 minutes, then dried at 100 °C for 1 hour in an oven. The dried straw was ground in a Dry Herbs Grinder (Vevor 2500G Electric Powder Machine) and sieved to obtain particles ≤0.6 mm in diameter. The solid phase, consisting of straw powder and corn starch, was mixed with various proportions to test the best configuration, then a solution containing water and glycerol was added (Table 1). The resulting NewStraw compound was then molded, manually pressed, and compression molded in a Multifunctional Heat Press (Vevor Multifunctional 5-in-1 Heat Press) at 120-150 °C for 15 minutes. The resulting panel was conditioned at room temperature and humidity for at least 24 h. A moisture absorption test was conducted to determine its moisture equilibrium, moisture content relative to weight under drying conditions, and density.

Table 1. Wet material proportions (% w/w)

Wheat straw dust	Corn starch	Citric acid	Glycerol	Water
27	**6**	4	1	**62**

Educational toy design

To integrate the material's production and processing into Corvetto's social fabric, an application scenario suitable for designing an artifact was identified: that of an educational toy. Given NewStraw resemblance to a particleboard, woodworking methods were employed as main processing techniques. The focus shifted to the toy industry, aiming to introduce the final product into primary schools in the district. The initial research investigated two educational key-points: the Montessori method and the development of cognitive-spatial skills. The former promotes the use of simple shapes and small sizes to stimulate children's creativity through joints [25,28]. About the latter, concepts like orientation and perspective were enhanced by introducing the kid to a three-dimensional play and collaborative activities with adults for spatial concepts absorption [26].

A prototype of each toy element was then realized starting from NewStraw panels measuring 300 x 150 x 5 mm using manual methods (hand sawing, sanding) and woodworking machinery, such as fretsaw and drill press.

Findings

NewStraw results

The primary objective of the experiment was to determine the optimal proportion of substances to achieve a satisfactory material in terms of aesthetic performance and apparent mechanical strength (Figure 1), aiming to maximize the concentration of wheat straw while minimizing the corn starch matrix phase. The chosen proportion, shown in Table 1, was the most effective, with a straw powder to corn starch ratio (dry weight) of 4.5:1, and a significant water content. High amounts of water are essential for the molding phase prior to heat compression molding, facilitating material compactness and shape retention. An excessive amount of straw compared to water led, indeed, to a poor malleability of NewStraw, making the molding process difficult. Pressure factors were also defined, so that the final thickness of the panel could be determined in advance.

Figure 1. NewStraw obtained with the defined proportions and process (Arioli, 2024)

The moisture absorption test, conducted at an average 50% relative humidity, revealed the material's high propensity to absorb environmental water.

NosEdu: Build Your Own Corvetto

By integrating the research findings and game concept development, a customizable city was created for children. Various game elements were designed to be assembled using simple joints, allowing the child to construct the final object. The child can then use their preferred coloring method to associate each generic game module with a real-world element. This should enable the child to create a personalized version of the Corvetto neighborhood, based on specific landmarks such as houses and schools, and to rearrange the remaining elements. Finally, the user might interact with the various game elements during play, enhancing engagement and learning (Figure 2).

Figure 2. Visualizations of the interaction between users and the educational toy (Arioli, 2024)

The product mock-up demonstrated adequate manufacturability through woodworking techniques, both manually and with machinery, enabling the development of the first prototypes of the educational toy “NosEdu: Build Your Own Corvetto” (Figure 3). The toy prototype received positive feedback from educational experts, aiding children in developing micromotor skills through various interlocking systems.

Figure 3. Some prototyped elements of the educational toy "NosEdu: build your own Corvetto" (Arioli, 2024)

Discussion/Conclusion

The NewStraw material proved satisfactory when evaluated against the initial hypotheses of straw waste quantity usage and social impact. It successfully incorporated a high content of wheat straw waste, 72% w/w under dry conditions, using simple, easily replicable processes and low-tech machinery. Feedback from social aid associations indicated its suitability for educational activities and workshops, possibly introducing at-risk school dropout youth to woodworking and creating new job opportunities. The material's immediate manufacturability enhances its versatility, allowing for diverse applications (biopanels, signage elements, roots trainer pots). Current research focuses on identifying alternative natural formulations to replace starch, thereby enhancing mechanical strength for structural purposes, and developing hydrophobic bio-based coatings to expand potential applications.

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Strawlife: new materials from agricultural waste for social reintegration and development

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Abstract
Environment and society are the two focuses of today's reality. On the one hand, we have an exhausted planet and on the other, we have a society in continuous and rapid development that is ill-suited to social fragilities. To transform these two different complexities into mutual values, StrawLife was born. By recovering the waste from the agricultural production of rice in the Parco Agricolo Sud Milano, it was possible to obtain new straw-based materials by involving the local fragile subjects in the production. The straw was treated with an alkaline solution, and it was softened to be mechanically processed obtaining a pulp and forming sheets of paper fabric. A second more rigid result was obtained by cooking the straw before being combined with a gel of water and starch. The two results were subsequently used to design products that responded to the needs of the local communities.

Keywords: *Rice straw; By-products; Agricultural waste; Circular economy; Social development.*

Introduction
In this historical period the management of plastics [1] represents an issue for society and the planet, and it becomes crucial to analyze and manage all the complexity of society in all its aspects. For instance, in structuring the goals of the 2030 Agenda, the United Nations touched on all the key points of global development [2]. One of the emerging complexities relates to population growth, which is expected to increase to 9 trillion by 2050 and 11 trillion by 2100 [3]. Increasing population possibly means coping with a surge in plastic management problems and growing demand for basic necessities such as agricultural goods. This requires an increase in production and, consequently, more waste. Like plastics issues, sometimes agriculture is a complex sector [4]. Within the latter, there is already a considerable generation of waste, classifiable as Crop Residue, Livestock waste, Agroindustrial waste, and Aquaculture waste [5]. The scraps from agricultural activities are not always easy to process. In some cases, the by-products obtained, such as bran derived from wheat processing, are still usable for food purposes or as fodder for animals [6]. In other more complex cases, dealing with these by-products is difficult since perceived and treated as agricultural waste that is difficult to manage, losing an opportunity to use valuable resources. The present research focuses on Parco Agricolo Sud Milano (Italy), identifying rice straw as the most common

by-product [7, 8, 9] which is for local producers to manage. The high silica content [10] (Figure 1) of rice straw makes it unsuitable as animal fodder as it's not digested by animals [11]. For the same reason, inclusion in the soil is a potential disadvantage: reintroducing the straw into the soil requires three months before starting a crop because otherwise rice straw would release harmful substances to the soil and the crop itself. [12]. Therefore, rice straw is usually burned destroying ecosystems and releasing toxic substances such as CO_2, N_2O, CH_4, CO, SO_2, and NO_X into the atmosphere [11].

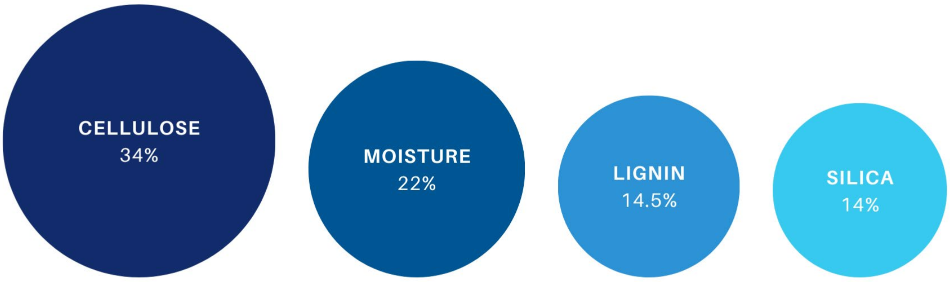

Figure 1: Chemical composition of rice straw. Other elements not in the figure are Ash, Nitrogen-free extract, Calcium, Phosphor, Potassium, Magnesium, Sulfur, Cobalt, Copper, Manganese [10]

StrawLife project represents an opportunity to transform critical material into a valuable resource by involving local associations and fragile individuals of the Corvetto community. Indeed, this is a complex area where several associations offer support to fragile individuals, supporting the poorest and excluded as well as combating school dropout [13, 14, 15]. StrawLife project intended to build a synergy between two problematic contexts: the upcycle of local agricultural scrap has been designed to offer a social aggregation opportunity, contributing both to the environmental and social development of this local context.

Methods

The experimentation conducted on rice straw was divided into two parallel tracks to further explore the possibilities and versatility of this waste. In both cases, rice straw was kindly provided by Riso Milano (Milano, Italy) farm.

For the first experiment, sodium carbonate (Na_2CO_3) from Solvay (Rosignano, Italia) was used. Previous studies already discussed the treatment of rice straw [16, 17, 18] and others were related to the solubility of sodium carbonate in water [19, 20] (Figures 2). Typically, the treatment of the fibrous material is performed at temperatures above 100 °C in an alkaline solution to dissolve lignin and soften the material. With reference to the analyzed studies, different concentrations of sodium carbonate (ranging from 3-20%) were tested, identifying a concentration of 5-6% Na_2CO_3 to water and a sodium carbonate solution: straw ratio of 30:1 (w:w) as optimal parameters for a satisfactory result.

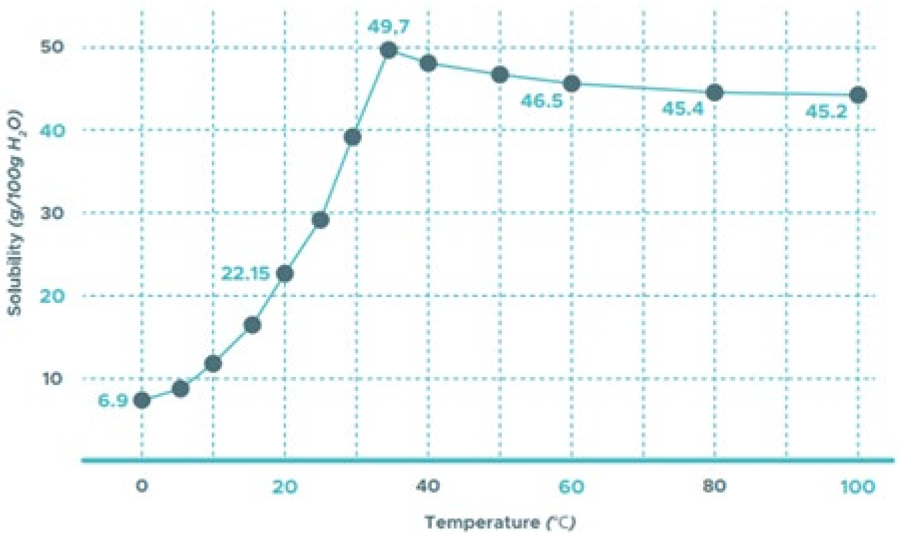

Figure 2. Solubility of sodium carbonate [20]

The straw was cut into 2 cm long pieces, cooked within the alkaline solution, and boiled at ambient pressure while maintaining a constant temperature of 100 °C for about an hour. The mixture was then rinsed with running water to remove residual lignin and neutralize the solution, and then mechanically processed with a blender to obtain a pulp. It was subsequently dispersed in water and sheet formed using a handmade papermaking loom. During this step, by varying the amount of pulp used to form the sheets, it is possible to obtain a paper-like (if the thickness does not exceed 2 mm) or a felt-like material (if the sheet thickness exceeds 2 mm). The formed material was dried in a VWR (Radnor, U.S.) VL 112 Prime forced convection oven at 80 °C for 30 minutes.

Figure 3: Wet pulp

Figure 4: Rice straw paper

Figure 5: Rice straw felt

For the second experiment, Carghill (Minneapolis, U.S.) iCoat cornstarch was dissolved in water with a starch:water ratio of 1:10 (w:w). The solution was then heated to 80 °C for five minutes until gelification. The straw, cut into 1-2 cm-long pieces, was cooked for one hour at 100 °C, then pulped with a blender and mixed to gelified starch with a straw:starch ratio of 2:1 (w:w). The mixture was kneaded and divided: one part was placed inside a mold and dried in the oven at 80 °C for 30 minutes (figure 6); a second part was thermopressed with the use of a 2-in-1 VEVOR (U.S.) heat press at 120°C for 15 minutes, resulting in a sheet with a thickness of 1.5 mm. (figure 7).

Figure 6: Moulded starch material

Figure 7: Thermopressed material

Within StrawLife project the aim was to involve fragile individuals from the local community in the Lodi-Corvetto-Chiaravalle district of Milan in materials production and in the applicative studies. By contacting two local associations (Associazione Nocetum and Soulfood Forestfarms), their needs were intercepted. The rice straw-based materials were applied designing for Nocetum a Tote bag using the rice straw felt and an Egg Box for Soulfood using the molded straw. For both products, the associations expressed their willingness to involve fragile individuals: the goal set was to involve Nocetum guests in the materials formation process and in product making by providing guidance and the necessary instrumentation. This provides the opportunity to transfer new knowledge, creating a circular economy within the local community, through social re-integration. Involving inexperienced individuals in the production phase means selecting simple equipment and substances that are as risk-free as possible.

Findings

The two experiments resulted in two different materials in terms of technical and aesthetic-sensorial properties. Straw treated with sodium carbonate has a different nature depending on the thickness of the sheet formed. When the thickness of the loom-formed sheet does not exceed 2 mm, the material (as demonstrated by characterization tests conducted with a load of 10 N/min using specimens with length, width, and thickness about 200x25x2 mm) is paper-like in properties and appearance: it can be folded (Figure 8), cut, and, due to its nature, it resists very little in contact with liquids. When the sheet exceeds two millimeters in thickness, it turns out to be more felt-like which can also be sewn (Figure 9) and presents higher resistance to liquid absorption. In both cases, a flame resistance test was done, from which it was observed that the material carbonizes without generating live flames (Figure 10). For the starch-rice straw, two different results were obtained: dried in stove, the material is light and soft, potentially useful when a cushioning effect is needed; dried using a heat press, the material resembles more of cardboard, which, however, cannot be folded since the fibers are held together by the outer starch structure. The resistance to liquids in each of the cases is good: immersed in tap water, it started to be fragile after 62 hours (figure 11).


Figure 8: Folded


Figure 9: Sewing


Figure 10: Burnt


Figure11: 62h wet

Conclusions

The results obtained from this project demonstrated how, from two complex and critical situations, it is possible to build on a different value by generating mutual support between the environment and the community, achieving the objectives of the 2030 Agenda in terms of the environment, circular economy, and social development. This is possible and replicable only when all members of a community are committed to a common good. By cooperating, institutions, universities, associations, companies, and individual citizens can generate enormous common value by transforming difficulties into opportunities. Both the materials made, and the products designed can be improved, making paper and felt more resistant to liquids and forming pressed sheets with a more stable structure. However, this early development was precious to proving the validity and enormous potential of the common support value which constitutes the heart of this project.

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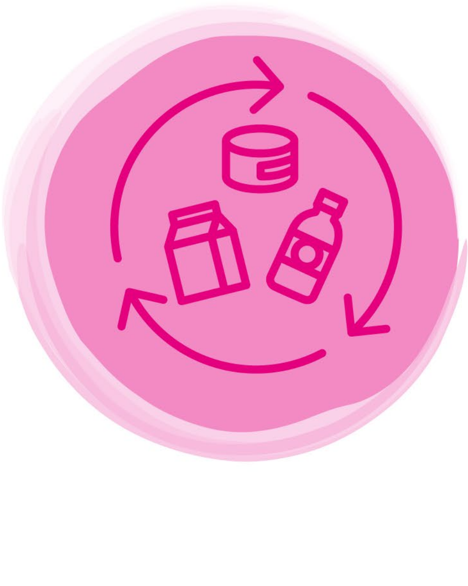
PACKAGING



Pomopla^2: Bio-based composite with tomato by products for circular packaging application

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Abstract

Due to the depletion of fossil resources, increased pollution of traditional plastics, and new regulatory restrictions, the research focused on the development of POMOPLA^2, a biocomposite based on a plasticized polylactic acid (PLA) matrix filled with tomato scraps for both flexible and rigid packaging. PLA is a versatile bio-based and biodegradable polymer with high strength, stiffness, and good processability. However, brittleness limits its industrial applications where plastic deformation at a high impact rate is required. A renewable plasticizer (LABD) was mixed with the PLA to overcome this drawback. Once the optimal extruded formulation was identified (PLA + 5% w/w LABD), powdered and dried industrial tomato peel waste was added as filler to the matrix. Following circular economy principles, the concept was to give a second life to tomato waste by developing POMOPLA^2, representing a promising substitute for current fossil-based plastics used to pack and sell fresh tomatoes.

Keywords: *Biocomposite; PLA; Plasticizer; By-products; Circular economy; Packaging.*

Introduction

In an era of escalating material consumption, the pressure on Earth's resources is becoming increasingly evident. Projections reveal that to sustain current lifestyles for a 2050 population of 9.7 billion, the resources of three planets per year will be required [1]. Global and European initiatives, such as the European Green Deal's Circular Economy Action Plan, seek to shift from linear to circular economic models, focusing on material recovery and carbon emission reduction [2]. Simultaneously, addressing the global food waste challenge is crucial, with 17% of food lost or wasted annually [3]. Target 12.3 of the 2030 Agenda aims to reduce food losses along production and supply chains, including post-harvest waste by 2030 [4], [5]. Agriculture generates substantial by-products, with up to 30% of processed food mass, and this has prompted the search for sustainable solutions, such as the conversion of organic waste into fillers for composite and biocomposite matrices [6], [7], [8], [9], [10], [11], [12], [13]. In this landscape, tomato waste emerges as a significant by-product, with promising properties, including strength, elasticity, hydrophobicity, thermal stability and good aesthetic-sensory attributes [14], [15], [16]. Several biodegradable polymers, particularly PLA, are used as matrices [17]. PLA, despite its biocompatibility and processability, is brittle with 10% elongation at break, limiting its applications [18], [19]. The addition of plasticizers, especially those derived from vegetable oils, improves PLA's flexibility, toughness, and ductility [20], [21], [22], [23]. This study explores a new natural plasticizer synthesized from linseed fatty acids and aims to valorize industrial tomato scraps to promote circular economy principles and sustainable agricultural packaging in line with European and global regulations.

Methods

Materials involved in the experimental activity include Ingeo PLA 6060D from NatureWorks (USA), linseed fatty acids esterified with 1,4-butanediol (LABD) plasticizer from A&A Fratelli Parodi S.p.a. (Italy) and powdered dehydrated tomato peels (TPs) from Conservas Marinete S.A. (Spain).

PLA 6060D pellets were ground into powder, TPs were micronized and dried, and materials were mixed according to predefined ratios. The extrusion of different formulations (see Table 8) was carried out using a SCAMEX twin-screw extruder under nitrogen at 50 RPM and a temperature range of 100-140 °C, and films were produced for subsequent characterizations. Nuclear Magnetic Resonance (NMR) analysis was conducted to check LABD plasticizer composition and evaluate PLA:LABD ratios. Scanning Electron Microscopy (SEM) was used to observe internal morphology, while tensile tests were performed to analyze mechanical properties. Thermogravimetric analysis (TGA) determined thermal stability, and Differential Scanning Calorimetry (DSC) measured glass transition temperatures. Migration tests assessed suitability for food contact applications.

The prototype package was designed as a tray (132 x 87 x 46 mm) with a thin film cover. The prototyping followed the mixture preparation procedure, with extrusion using a co-rotating twin-screw extruder equipped with a 1.75 mm die suitable for 3D printing. After air cooling, the extruded material was 3D printed with a Sharebot Next Generation printer using Slic3r software. The top film was formed with a CARVER 4122 hot press, applying a 2-tonne load at 160 °C for 10 minutes.

Table 8. Extruded formulations

	Extruded formulations
1	Pure PLA
2	PLA + 5% w/w LABD
3	PLA + 10% w/w LABD
4	PLA + 15% w/w LABD
5	PLA + 20% w/w LABD
6	PLA + 5% w/w LABD (with respect to PLA) + 5% w/w tomato waste (with respect to the whole material)

Findings

The characterization analysis revealed that POMOPLA^2 (PLA^2 + 5% w/w TPs) exhibits superior properties for food packaging applications, a significant increase in toughness of approximately 485% and a consequent 177% higher elongation at break, compared to 17% for pure PLA. The addition of tomato peels improves the internal morphology of the material decreasing the phase separation between PLA and plasticizer. Moreover, the tomato by-products give a bright orange hue to the material, serving as a recognizable indication to consumers of the composite naturalness and compostability.

Figure 5 shows the assumed POMOPLA^2 life cycle. Due to the circular approach applied, the scraps (peels) are exploited and reused to manufacture the biocomposite. The processing involved extrusion at low temperatures compared to traditional plastics (which can exceed 200 °C) [24]. This reduction implies energy saving for the production plant, potentially lowering the production's environmental footprint. The extrusion process outputs can be pellets, films, and sheets necessary for the fabrication of both rigid and flexible tomato packaging. Through a thermoforming process, it is possible to obtain the desired shape with POMOPLA^2 sheets. In an ideal circular system, if POMOPLA^2 passes the biodegradability and compostability tests, the packaging after use could be sorted into the organic waste fraction together with the remaining tomato residues (branches, peels, etc.). In industrial composting plants at controlled temperatures and humidity, the organic waste is processed to obtain compost for a new agricultural production. In conclusion, POMOPLA^2 promotes a sustainable cycle that starts with natural materials and finally returns nutrients to the soil, thereby closing the loop in an environmentally responsible manner.

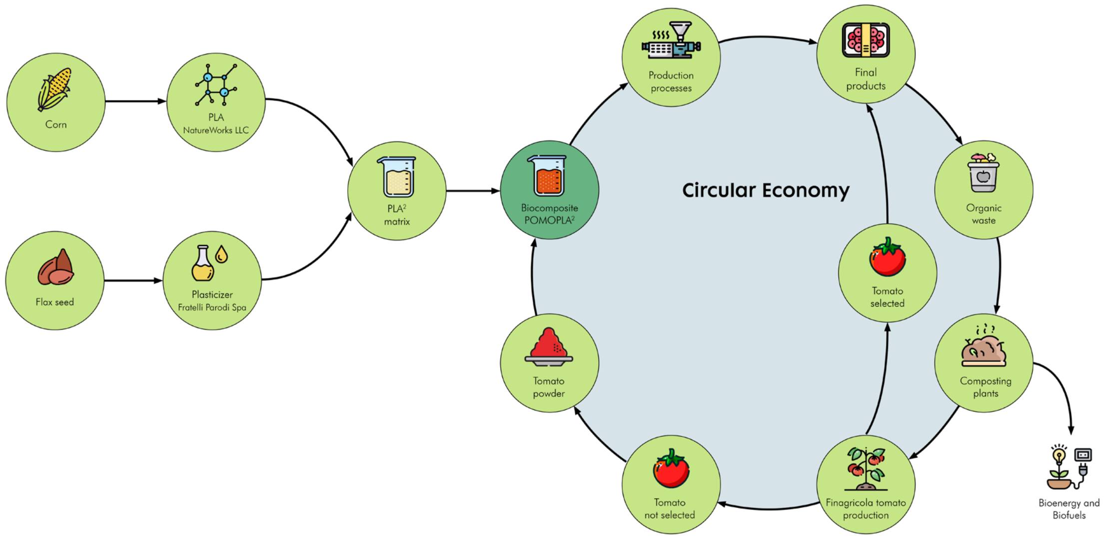

Figure 5. Ideal lifecycle of POMOPLA^2

As described above, POMOPLA^2 with 20% w/w of tomato waste was used for prototyping the packaging tray, taking advantage of the higher rigidity and the more natural and opaque appearance of the material. Alternatively, the transparent and flexible biocomposite with 5% w/w of tomato peels was employed to make the thin film (flexible packaging) that seals the tray on the surface (see Figure 6).

Figure 6. POMOPLA^2 final packaging prototype

Conclusion

POMOPLA^2 stands out as a circular and environmentally friendly alternative to traditional plastics, exploiting the naturalness and potential sustainability of biobased and biodegradable components. By adjusting the composite formulation, flexibility and toughness can be modulated, expanding the range of packaging applications. Mechanical tests confirm that the incorporation of vegetable waste maintains the strength of the matrix, resulting in a lightweight and flexible material. The adoption of

POMOPLA[2] aligns with resource efficiency targets and the European Green Deal principle. Furthermore, its adaptability to existing technologies and distinctive aesthetics encourage user awareness and waste-sorting practices. Future efforts include further testing to validate its suitability for food contact and composting, as well as environmental impact assessments (using the LCA method).

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The complex field of smart label and packaging in food industry: a systematic literature review for a taxonomy proposal

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Abstract

The packaging industry is evolving significantly due to market demands and digitization, and labels are playing a crucial role in engaging consumers and assessing product sustainability. Regulatory pressures urge companies to adopt ethical reporting tools like Global Reporting Initiative (GRI) standards. Despite the push for digital transformation, businesses have not unified solution to meet consumer, regulatory, and technological needs. In the scientific community, defining smart labels and packaging remains complex, with conflicting opinions. The lack of guidelines and best practices for supporting business in sustainable smart label design further complicates implementation. Trying to fill this gap, this study provides an overview of the performance of the literature on the topic, proposes definitions of smart labels and packaging and shows which technologies, and their characteristics, can be used for the design of sustainable smart labels, based on the needs of interested parties and/or consumers. Following a structured methodology, the study analyzes the body of knowledge and proposes a taxonomy to clarify concepts in agri-food scenarios and then proposes a design of food smart label.

Keywords: *Industry5.0; Smart packaging; Consumer; ICT; Sustainability; Agri-food.*

Introduction

Fast The packaging industry, which includes packaging, labels, and labeling processes, is undergoing significant evolution nowadays driven by market needs and the digitization process. Labels play a fundamental role in current corporate marketing strategies aiming to make the end customer a co-actor and protagonist of the product development process, according to a 4.0 marketing approach [3]. Customers are increasingly interested in knowing more information and details about the products they buy. In particular, in the agri-food sector, consumers awareness is triggering numerous market trends, showing consumers even more interested in consulting packaging and labels, accessing to product information, to assess the sustainability of the product (e.g., origin, certifications, sustainability of supply chains, environmental impact of the product and its packaging) [12]. Given regulatory pressures and national and international policies, companies should equip themselves with tools that help them in implementing ethical reporting obligations such as ethical balance sheets and sustainability standards useful for the certification of strategic actions (Global Reporting Initiative (GRI) standards, including GRI417 which defines and regulates Marketing and Labeling actions). In addition to regalement and policy pressures, companies are called to answer to the digital transformation which is even more pervasive. Technologies deriving from the Industry 4.0 paradigm, are useful to companies for the shift towards the Industry 5.0 paradigm (such as the use of RFID for product tracking by all stakeholders in the supply chain or QR codes to provide more information to end consumers from a value chain perspective) [1]. Today, although companies want to be effective in the market by embracing digitalization, there is no clear vision on a single tool capable of meeting, at the same time, consumers' informational needs, regulatory requirements, and technological needs. Additionally, in the international scientific panorama, many authors are trying to define new concepts of smart labels and smart packaging, bridging the gap between traditional and intelligent labels and packaging, which generated entropy [10]. Academics revealed a high level of complexity with conflicting opinions in the definitions of these new concepts. Moreover, in academic scenario and industrial one, the absence of guidelines for supporting businesses in the proper integration of technologies for the design of smart labels or packaging and the absence of clear best practices for their implementation are highlighted. Starting from these evidences, this experimental thesis work built on the following research question guiding the study: How to design a smart label in sustainability way?

Methods

In order to achieve the purpose of the study, a systematic literature review (SLR) method, with PRISMA guidelines, was chosen. SLR allows the identification of the boundaries of existing knowledge and the sharing of the results of other closely related studies [11]. Conducting a good literature review requires a structured methodology, consisting of defining the appropriate search keywords, along with a literature search and analysis [13]. A methodological framework was built to show how the research was developed through five phases. In this framework, shown in the Figure 1, each phase was put in communication with the logic of the response flow to the research questions.

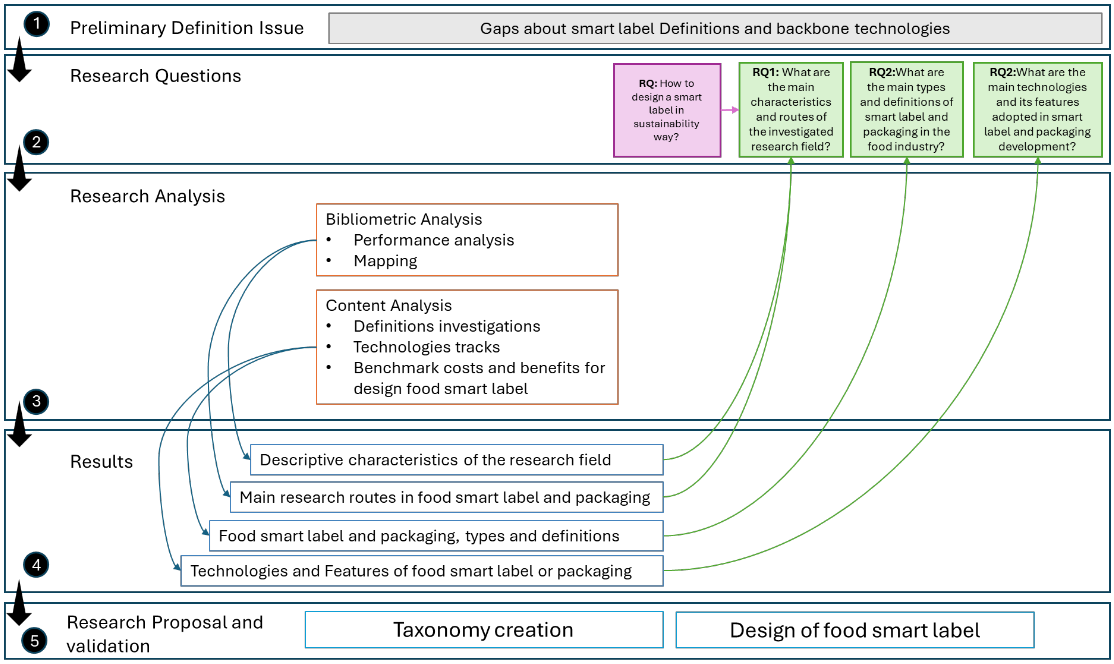

Figure 7. Methodological framework (our production)

In particular, regard SLR, the database from which extracting the bibliographic material to be analyzed was chosen: Scopus (https://www.scopus.com) managed by Elsevier. The research was released in March 2022. The search in Scopus was conducted according a specific and advanced query in 'Article title, Abstract, Keywords' field of search: TITLE-ABS-KEY ("Smart Label" OR "smart Packaging" OR "intelligent packaging" OR "intelligent label" AND "food"). The search was set with temporal restriction deciding to eliminate the papers prior to 2011, because the Industry 4.0 paradigm had not yet been defined before the above mentioned year [4]. The selected keywords allowed to retrieve an initial sample of 684 papers. Inclusion and exclusion criteria were applied (limit to English language and not in focus with the topic of the present work) to obtain final sample of 50 papers.

Findings

Bibliometric analysis: performance and mapping findings

Leveraging on a performance analysis, based on several bibliometric indicators, "Scientific production overtime", "Country scientific production", "Impact on subject area", "Top five most productive journals and quality indicators" and "Most global cited documents" fields of interest were analyzed in order to build a proper frame of the scientific production on the topic. Figure 2 shows an infographic visualization about the results.

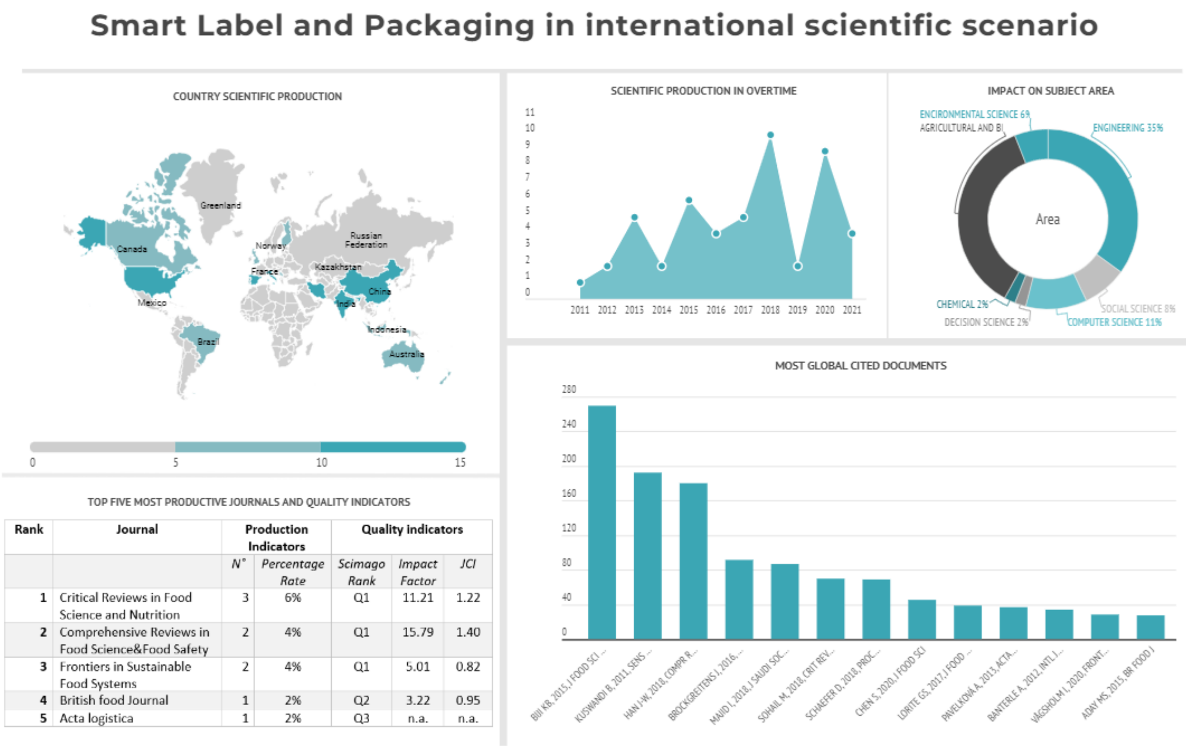

Figure 8 Infographic visualization about bibliometric performance results (our production with bibliometrix tools)

The Science mapping analysis was carried out through cluster analysis using the VOSViewer software with the aim of investigating which are the research routs addressed in the field. The Figure 3A shows the co-word (keyword co-occurrence) network highlighting five clusters (red, green blue, yellow, purple) which involved a total of 85 terms. The *Cluster 1* contains all the terms related to the concept of innovative packaging and leverages on technologies (especially referring to active packaging) with the aims for performing quality control and for communicating particular product information like its shelf life. The *Cluster 2* highlights the usage of intelligent packaging for monitoring of products physical conditions and communicating information about them along the supply chain through the application of tagging and sensor technologies in order to monitor food changes for greater safety. The *Cluster 3* includes terms relating to the use of technologies enabled for sharing product information, such as the origin underlined by the "coo information" (Country of Origin information), directly to the final consumer. In the *Cluster 4* the technological aspect is declined with a view to enabling technologies in the logic of environmental sustainability, detected by food waste and food loss, but also economic through the digitization of agricultural processes and traceability that allow to reduce costs throughout the supply chain agri-food. The *Cluster 5* is aimed at studying the effects of the distribution of technological systems operating with IoT in terms of impact on the entire ecosystem and that they can also be perceived as barriers. Figure 3B instead shows the temporal evolution of the terms present in the map allowing to have information about the actuality of each term. From the latter it is evident that most of the themes are not exactly recent with the exception of the co-words "sustainability", "digital agriculture technologies" and "food loss".

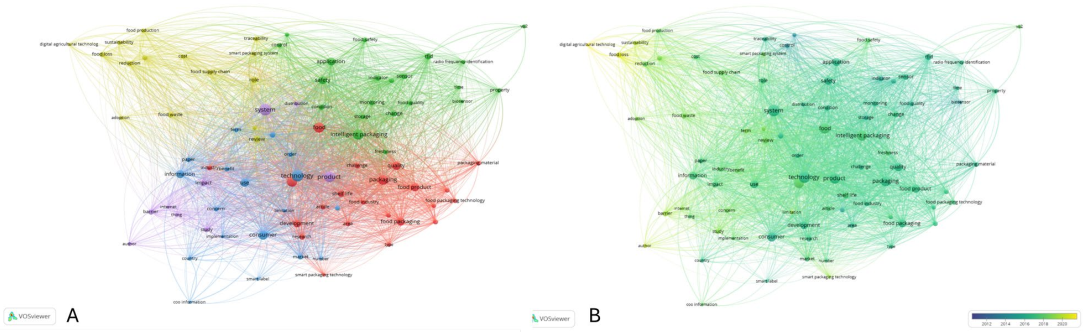

Figure 9. Co-word (keyword co-occurrence) network (A) and overlay visualization map (B) (our production with VOSviewer tools)

Content Analysis: Definition of food smart label and packaging, technologies and its features

From content analysis performed on the final sample of papers, the definitions of “Smart Label” the relevance of the word "information" is extracted. While, as anticipated by Noletto's [10] study, the definition of "Smart Packaging" encompassed two other concepts: "Active Packaging" and "Intelligent Packaging". These can be understood as two definition micro-categories in which the characteristics of “Smart Packaging” were classified separately. There is first evidence of a connection between the word "information" characterizing the definition of "Smart Label" and the same in that of "Smart Packaging", in particular when the concept of "Intelligent Packaging" is present in this. Downline these evidences, the sets of definitions “Smart Packaging” and “Smart Label” can be represented as separate but with common boundaries. Another evidence deriving from same analysis shows that the definition of "Smart Packaging" incorporates the concepts of "Active Packaging" and "Intelligent Packaging". These definition micro-categories refer to specific functions that a "Smart Packaging" encompasses respectively: in terms of control and communication to stakeholders about quality of the product contained in the packaging [2;8], both in terms of information communication and throughout the supply chain [14]. The word "information", that emerged in the definition of "Smart Label", returned here redundant in the definitions of "Intelligent Packaging [7;9]. Important evidence in the definition of [14] in which the Intelligent Packaging was explicitly associated with a small and inexpensive label: "Intelligent packaging (IP) is typically defined as small, inexpensive labels or tags". Content analysis allowed to track technologies involved in smart label or smart packaging with a differentiation between Information Communication Technology (ICT) and Biotechnology. With regard to ICTs, results show that in 52% of cases RFID was identified as an enabling technology, followed by 13% of Barcodes and 11% QR-Code. Technologies such as NFC, IoT and Electronic Article Surveillance - the latter described simply as electrical devices for control but not well characterized - also stand out with a frequency of 5%. Most of these ICTs fall within the technologies of the industry 4.0 scenario. From the frequency analysis of the Biotechnologies, it was interesting to note how the distribution was more homogeneous. The 34% figure stands out for the Time-Temperature Indicators (TTI) which are devices that are frequently implemented with RFIDs to monitor the temperature of food over time [6]. On the threshold of 20% or so instead we see the Freshness Indicators, Biosensors and Gas Indicators - devices related to the Biomaterials field. A remaining 9% indicates the presence of Nanosensors, a technological branch currently undergoing substantial development in the agri-food context [5]. Downstream about technologies tracking, and in particular for both ICTs the features of the technologies and their relation of integration, stakeholders influence and price in smart label and packing applications were presented below in Figure 4.

ICT	FEATURES OF ICT								ICT								STAKEHOLDERS			PRICE		
	Data carriers	Storage Capacity	Database	Data nature	Distance Reading	Security	Monitoring of food supply chain	Monitoring of food spoilage	Barcodes 1D/2D	QR-Code	RFID	NFC	GPS tags	Block Chains	AR	LEDs	Customer	Company	Supply Chain Actors	HIGH	MEDIUM	LOW
Barcodes 1D/2D	X	X	X	X	X	X	X	-	-	-	-	-	-	X	-	-	X	X	X	-	-	X
QR-Code	X	X	X	X	X	X	-	-	-	-	-	-	-	X	-	-	X	X	-	-	-	X
RFID	X	X	-	X	X	X	X	X	-	-	-	-	-	X	-	X	X	X	X	X	X	-
NFC	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	X	-
GPS tags	-	-	X	-	-	X	X	-	-	-	-	-	-	-	-	-	-	X	X	-	X	-
Block Chains	-	-	X	-	-	X	X	-	-	X	X	-	-	-	-	-	X	X	-	-	X	X
AR	X	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	X	X	-	-	-	X
LEDs	-	-	-	-	-	X	-	X	-	-	X	-	-	-	-	-	X	X	X	-	X	-

Figure 4. ICTs characterization (our production)

Discussion

This study provided in one point the knowledge that satellites around the concept of smart labels, smart packaging and associated nuances of meaning, going to enhance these concepts. Through critical analysis and by identifying the discriminants of these concepts, a taxonomy was proposed in Figure 5, capable of bringing out the characteristics that mark the definition boundary of smart labels, smart packaging and its active packaging micro-categories and intelligent packaging. Thanks to the proposed definitions taxonomy it was possible to highlight the new intelligent label concept which is necessary to clarify the entropy detected in the literature.

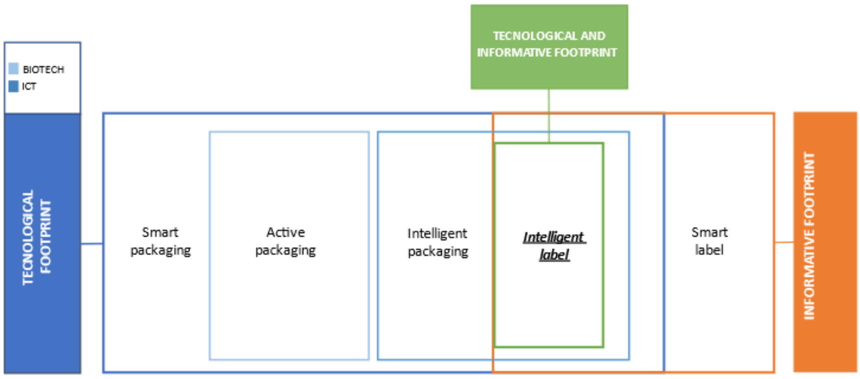

Figure 5. Proposed Definitions Taxonomy (our production)

Downstream, we proposed a set of definitions derived from the proposed taxonomy. Smart Label: it can be understood as a technological system that provides consumers with far more information than a traditional label ever that can be integrated with the packaging to facilitate communication and the sustainability. Smart Packaging: it can be understood as a system designed to monitor information on food quality and / or monitor the condition of packaged foods to provide information during transport and storage. A collective term used to group together some emerging typologies of technological packaging that interact with the consumer and / or the product in an enhanced way from which called “Active packaging” and “Intelligent Packaging”. Active Packaging: was created with the aim of satisfying consumer demand to use recyclable and biodegradable materials for packaging. It implies the interaction between the product, the packaging and the environment with focus on innovative materials and design packaging development in order to maintain or improve the condition of packaged foods incorporating sensors and biotechnology. Intelligent Packaging: it could be defined as a packaging system capable of performing intelligent functions, such as small, inexpensive labels or tags that are attached to primary or secondary packaging in order to facilitate communication throughout the supply chain. It’s technologies integrate intelligent features such as tracking, communication and logging in order to provide food quality information to interested parties (e.g. producers, retailers, consumers), facilitating decision making it. Intelligent Label: it could be defined as a label capable of performing intelligent functions through the integration of ICT in order to facilitate decision making and communication throughout the supply chain and also the value supply chain. Thanks to ICT features verticalization in Figure 6 was proposed a food smart label design. In particular, a Solution Proposal include: (a) QR-Code that satisfies the customer's needs to have more information on the product and those of the company on marketing actions, (b) RFID that meets the company's needs for traceability throughout the supply chains and those of supply chain actors by optimizing operations, (c) GPS tags to monitor the location of the product by the company and control efficiency logistics but also the important times for the safety of the food product and finally (d) the Blockchain that ensure the truthfulness of various information on the product, for example the origin, protecting the company and stimulating the customer to purchase.

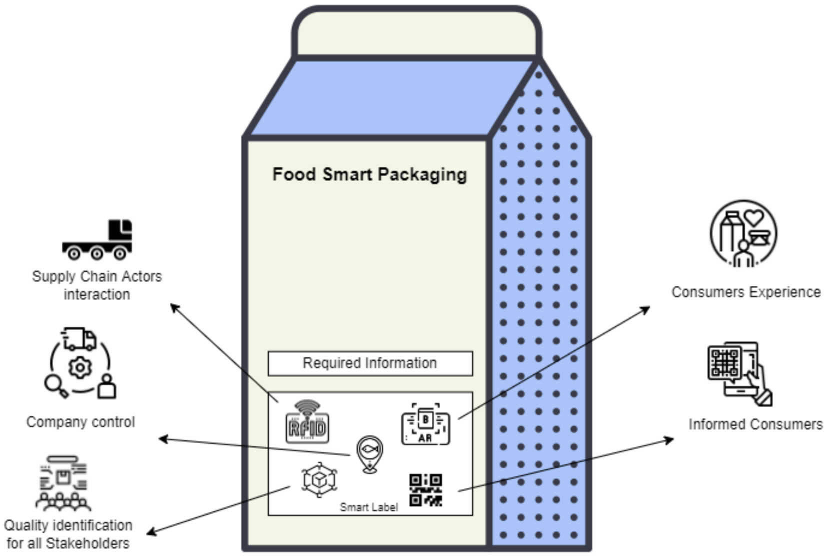

Figure 6. Food Smart Label Design proposal (our production)

From our insights, theoretical and practical implications arose. The results of this study could benefit researchers, academics and practitioners, helping them to use a correct term for a specific typology of Label aligned with Smart concept. The taxonomy should not be seen as a mere extension of a dictionary with the ultimate beneficiaries only academics but also provides support to the knowledge of practitioners. In particular, the aspect of technological and informational discriminants guide companies to the correct use of terms and knowledge in order to avoid miss leading. Furthermore, the discriminant linked to technologies shows that the different families of technologies refer to categories of smart packaging with different characteristics and functionalities.

Conclusion

The study highlighted the gap in current smart label design, focusing on collecting information for the supply chain but neglecting the end customer. Utilizing technologies from industry 4.0 without clear guidelines has made marketing strategies challenging. The lack of tools supporting the consumer's technological and information needs, along with the absence of sustainability concepts, have been addressed in the new smart label design. Through extensive analysis, key insights were gathered on smart labels, intelligent packaging, the importance of information, and the technologies involved. The study proposes a new innovative smart label design that addresses these gaps and offers potential for future scalability and development in various scenarios. By answering the research questions and analyzing the scientific landscape, the study aims to bridge the gap in smart label design and enhance the overall efficiency and effectiveness of the agri-food supply chain.

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Improvement of kraft paper performance by deposition of biodegradable coatings for food packaging applications

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Abstract
The packaging industry is increasingly adopting paper due to its environmental benefits. Although paper is biodegradable, compostable, recyclable, and has good mechanical properties, its hydrophilic nature and fiber porosity limit its barrier properties and water resistance. This study investigates enhancing Kraft paper (KRP) functional properties by depositing aqueous coating solutions of an ethylene-modified polyvinyl alcohol (modPVA) at various concentrations (10% to 20% wt/wt) for food packaging applications. The coatings significantly increased the paper's grammage and thickness, reduced water absorption, and improved air resistance. The impregnation degree of the coating was found to decrease by increasing viscosity of the coating solution. Preliminary results suggest that these biodegradable coatings offer competitive barrier properties, supporting sustainability and the circular economy model.

Keywords: *Barrier coatings; Recycling; Food packaging; Coated paper; Biodegradable.*

Introduction
The packaging industry is increasingly favoring paper due to environmental concerns. In 2022, the global paper and paperboard packaging market was valued at USD 210.29 billion, with projections to reach USD 299.87 billion by 2029 [1]. Paper's biodegradability, compostability, recyclability, and good mechanical properties contribute to its high consumer acceptance and alignment with the circular economy model. However, its hydrophilic nature and fiber porosity limit its barrier properties and water resistance, leading to potential loss of physical and mechanical strength when exposed to moisture [2]. Traditional petroleum-based plastics widely used in combination with paper such as polyvinyl chloride, polystyrene [3], synthetic waxes [4], and fluorine-based derivatives [5], showed severe limitations because the fossil-oil resources, poor recyclability, and environmental concerns arising from their slow degradation.
Coating technique, particularly, has been individuated as promising in obtaining more flexible and lightweight paper-based structures meeting circularity and extending product shelf life [6]. Current challenges in coated packaging paper involve selecting eco-friendly coatings that are easy to process for developing simple structures with

minimal different materials and additives for sustainability and cost-effectiveness. For those reasons, increasing interest is addressed in high-performance biodegradable coatings based on renewable resources, such as polysaccharides [7], proteins [8], lipids [9] and bio-polyesters [10] to impart multiple technological functionalities like gas and moisture permeation resistance, hydrophobicity, antimicrobial protection, scratch resistance, and cohesive strength to paper-based packaging surfaces, while providing the environmental benefit of recyclability [11]. Polyvinyl alcohol (PVOH) stands as an interesting biodegradable option for eco-conscious and functional paper-based packaging solutions, providing protection against gas permeation, resistance to external agents, and improved adhesion, owing to its film-forming ability and high barrier properties [12]. Moreover, the deposition of a water-soluble polymer could preserve the recyclability of the base paper substrate, allowing for easy removal through a hot washing step and the recovery of pure pulper fibers.

In this scenario, this study aimed to develop biodegradable coatings of ethylene-modified PVOH at various concentrations (10% to 20% wt/wt) on a high-quality Kraft paper with the goal of enhancing its overall functional properties and extend its application as a food packaging material.

Methods

KRP with a nominal grammage of 100 g/m² (Netuno Sp.z o.o.m, Wojska, Poland) was coated with coating solutions at different concentrations of Exceval AQ-4104 (Kuraray Europe GmbH, Hattersheim), a fully hydrolyzed (98.0-99.0 mol%), water-soluble, chlorine-free polyvinyl alcohol (modPVA) that has been modified by adding ethylene moieties to the chain to reduce its moisture sensitivity, as reported in the technical sheet provided by the supplier.

Realization of modPVA coatings

ModPVA powder was dissolved in deionized water at 95°C for 15-20 minutes at concentrations of 10%, 15%, and 20% wt/wt. The solutions were then applied onto paper using a K Hand Coater (RK, Printocoat Instruments Ltd., Litlington, UK) equipped with a 0.64 mm wire diameter rod. After application, the coated samples underwent drying at 120°C for 3-4 minutes, followed by overnight storage at room temperature to ensure complete drying. The developed structure layout is schematized in Fig. 1 while, in Table 1 are listed the name of the produced samples, their grammages, total and coating layer thicknesses.

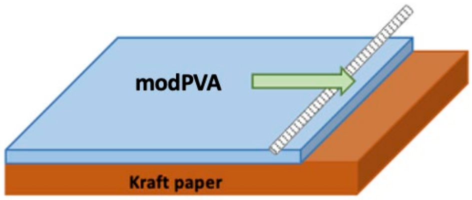

Figura 1. Structure of the developed systems

Table 9. Structure of the development systems

Sample	modPVA conc. [%wt/wt]	Grammage [g/m^2]	Total thickness [μm]	Coating layer thickness [μm]
KRP	-	104.3 ± 0.8	151.3 ± 2.8	-
KRP10	10	113.2 ± 1.5	158.3 ± 3.6	7.0 ± 4.6
KRP15	15	116.0 ± 1.8	159.6 ± 1.7	8.3 ± 3.3
KRP20	20	121.3 ± 2.0	162.0 ± 2.2	10.7 ± 3.6

Characterization techniques

The average thickness, based on ten measurements, was determined for each sample using a digital micrometer (ASTM D 645M). The grammage analysis was performed in accordance with the ASTM D646-96 and calculated as the ratio of the weight of coated samples after drying (in g) to the measured surface (in m^2). The difference in the basis weight before and after the application of the coating was used to determine the coating load, always expressed in g/m^2.

Preliminary rheological characterization of the coating solutions was conducted by using a stress-controlled rheometer, Malvern Kinexus Pro (NETZSCH - Gerätebau GmbH, Selb, Germany). A 50 mm diameter cone plate geometry was used, while the temperature was kept at 25°C. Shear viscosity values were taken from the down shear ramp from 100 to 1 s^{-1}.

To quantify the portion of the coating solution penetrated inside the pores of the substrate, the percentage of impregnation (IM%) of coating material was calculated in accordance with a procedure described by Gastaldi et al. (2007) [13], by using the formula:

$$IM\% = 100 * \frac{\rho_c - \rho_f}{\rho_f}$$

where ρ_c and ρ_f [dry matter/cm^3] were evaluated as the inverse of the slope of the linear curve fitting the increase of paper thickness and as the inverse of the slope of the linear curve fitting the increase of self-supported film thickness, both as functions of deposited coating weight. For visual observation of the penetration thickness of the coating solutions, samples were adequately prepared exploiting the use of a Blue Patent

V dye and then observed by means of a Zeiss Axioskop microscope (Carl Zeiss Vision, Germany) in the form of thin slices.

The water absorption capacity was assessed following the UNI EN ISO 535:2014 standard procedure, by using a Cobb equipment (Enrico Toniolo srl. Milano, Italy) to define the amount of water, expressed in grams, that is taken up by a defined area of a paper (1 m^2) through one-side contact with the liquid, within a certain amount of time (60 seconds). Air resistance was determined following the UNI EN ISO 5636-5:2014 standard procedure and using a Gurley-type apparatus (Enrico Toniolo srl, Milano, Italy) to measure the time taken for 100 cm^3 of air to pass through the paper surface.

Results and Discussions

The uncoated KRP initially presented a grammage of 104.3±0.8 g/m^2. The deposition of modPVA was responsible of a significant rise in grammage with the increasing concentration of the polymer in the coating solution, reaching a maximum value of 121.3±2.0 g/m^2 for the KRP20 sample (Table 1). Similarly, the thickness of KRP increased up to 162.0±2.2 μm when coated with 20% wt/wt of modPVA (Table 1).

Viscosity affects the solution's ability to penetrate paper fibers, fill voids, and influence the choice of deposition technology for uniform coating layers and the impregnation level of coated paper samples [7]. Preliminary rheological characterization of the coating solutions showed an exponential increase in viscosity with increasing modPVA concentration in the coatings. This viscosity trend resulted in a linear decrease of the IM% value across the samples. In particular, a 45% reduction in the IM% value was found by doubling the polymer concentration in the coating solutions from 10 to 20% w/w. Optical microscopy of the coated samples revealed a decrease in impregnation depth as the concentration of modPVA and consequently the viscosity increase confirming the results regarding IM%. Fig. 2 shows the cross-section of the KRP15 sample as an example, with the blue-colored coating solution penetrating the structure and the pores of the substrate.

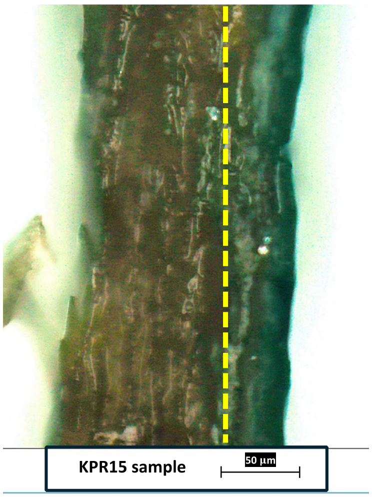

Figure 2. Optical micrograph of cross-section of KRP15 sample

The Cobb value measures water penetration resistance of paper-based materials. The initial $Cobb_{60}$ value of the Kraft paper equal to 45.17 g/m^2 undergoes a gradual decrease as the concentration of modPVA in the coating solution increases, with percentages of reduction ranging from 47.5 to 57% with respect to the neat paper for KRP10 and KRP20 samples, respectively. This trend is related to the higher coating load deposited on the surface that can reduce the penetration of liquid water [7].

Paper's air permeability impacts its performance and machinability. The low resistance to the air passage of the base paper (78.7 s/100 cm^3), attributed to its porous structures, increases by two orders of magnitude by adding the polymeric coating, reaching the maximum value for the KRP20 sample. This is due to effectively coverage of the surface and pore filling operated by modPVA solutions, limiting air passage [14].

Conclusion

Kraft paper was functionalized by the deposition of solutions based on a biodegradable PVOH modified with ethylenic insertions at different percentages (from 10% to 20% wt/wt) enabling to improve the functional properties of the starting substrate and extend its use as sustainable food packaging. The impregnation degree of the cellulosic substrate was found to be highly dependent on the viscosity of the coating solution. Coatings significantly reduced water absorption (up to 57% for KRP20) and increased air resistance by two orders of magnitude across all coated samples compared to the base paper. Ongoing research focuses on evaluating oxygen and water vapor barrier properties for potential food packaging applications. Preliminary findings show that the polymeric coating improves these properties, with Oxygen Transmission Rate (OTR) and Water Vapor Transmission Rate (WVTR) values comparable to or better than those of biopolymers like polycaprolactone, PCL and polybutylene adipate terephthalate, PBAT commonly used in food packaging [15].

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The importance of food packaging and consumer perception for a sustainable supply chain

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Abstract

This paper examined supply chain challenges, with a particular focus on food packaging and its influence on consumer perceptions, which can significantly impact sustainable development. The research aimed to emphasize the vital role that food packaging plays in preventing waste, reducing food loss, and mitigating environmental effects across the supply chain. The study was grounded in a review of academic literature, which guided the development of a multiple-choice questionnaire distributed to 275 consumers. The research also incorporated an analysis of Environmental Product Declarations (EPDs) from the "EPD International System" platform, providing insights into how companies in the industry communicate sustainability. The results revealed that consumer perceptions, awareness, and engagement are crucial factors in the acceptance or rejection of various packaging materials, functionalities, and technologies. The complex dynamics between consumers and packaging can hinder the progress of a circular economy. Therefore, the success of sustainable supply chain initiatives is closely linked to consumer involvement in sustainable practices and the cultivation of a strong, positive relationship between consumers and companies.

Keywords: *Supply chain; Food packaging; Circular economy; Sustainable Development; Consumers'Perceptions.*

Introduction

The present research was devoted to investigating supply chain issues, with particular attention directed toward food packaging and how the perceptions developed by consumers in relation to them may influence the dimension of environmental sustainability. This topic also turns out to be of great topicality, as over the last few years the supply chain has been faced with numerous challenges related to a series of natural, economic and geopolitical events that are difficult to predict and have undermined its efficiency and effectiveness [1]. In this context, the food packaging system and its related logistical functions are among the major players in the supply chains, and its sustainability relies not only on a careful choice of usable materials, but also on a careful analysis of its functionality throughout the entire life cycle, including post-consumer [2]. The research conducted found that in the past, food packaging has often been regarded as a kind of "necessary evil," that is, as something that should be minimized as much as possible [3]. The trend has been to focus on the direct environmental impacts arising from food packaging, namely those related to their production, the amount of material used and their disposal, when, in fact, they possess a number of functions that give them great potential in contributing to environmental sustainability. Hence the need to embrace a broader view that also includes indirect environmental impacts from functions that can contribute to reducing food loss and waste and abating related environmental impacts [3]. The study found that the contribution of indirect environmental impacts is in most cases higher than the direct ones. These impacts also include a social and ethical dimension, as food losses and waste threaten the food balance of the growing global population [4]. The problem is that until consumers are sufficiently aware of these dynamics there will always be resistance in achieving sustainability goals [4]. The best sustainable solutions should be identified by involving end consumers, but in the research it was found that the role of consumers has been little explored in the inherent supply chain and logistics literature, often relegating them to a more passive than active role in co-creating value [5]. In addition, the relationship between consumer behavior, the packaging system and related indirect impacts on the environment has often been overlooked in life cycle assessments of food products [6].

Methods

For the development of this paper, the academic literature was analyzed, which included studies, reviews and, in general, publications mainly produced in the last decade, mainly from the "Web of Science" database. Based on the literature, a research questionnaire targeting consumers was then structured and administered between July 26 and August 1 2023 in an online mode, mainly through some social media. It was structured into 35 multiple-choice questions and involved 275 respondents. The first 8 questions focused on delving into the sociodemographic profile of consumers, while the remaining questions focused on investigating consumers' perceptions of aspects related to the main functions of food packaging and related materials, processes that generate food waste and loss, purchase intentions, willingness to pay, and, in general, levels of awareness about the environmental sustainability of packaging. This was also complemented by an analysis of what is communicated by companies belonging to the sector through Environmental Product Declarations (EPDs) published in the "EPD International System" international platform.

Findings

Regarding the sociodemographic profile, the survey showed that the majority of respondents were young to middle-aged and more than half were women. Overall, the majority indicated that they had a medium to high level of education, and from the point of view of employment status, most stated that they were employed or engaged in a course of study. The sample was more concentrated in cities with a population size above ten thousand, while in terms of geographic area, the majority was concentrated in urban and peri-urban areas. Finally, household size was generally found to be larger than two members, and regarding food preferences, a balanced preference emerged between organic and conventional food consumption.

Subsequent questions showed that consumers attach great importance to the sustainability of packaging in their food purchasing choices. All the four main functions of food packaging most mentioned in the literature were given much consideration. In particular, the functions of protection/containment were considered the most important, and with regard to these, the needs related to hygiene and safety and the needs for loss prevention, product waste, emerged most prominently. In the handling facilitation function, innovative containment was favored, while in the communicative function of packaging, the graphic aspect was considered much more attractive than voluntary sustainability information. In relation to which aspects of the packaging material are most considered in the purchasing phase, the recyclability of the material was considered the most by the majority than the already recycled materials, biodegradability and compostability. Consumers' perceptions of which process was most responsible for producing food waste indicated mostly household consumption, followed by food processing/production and retail. Going deeper into the main causes of food waste at the household level, more than half of the respondents indicated excessive purchases, followed to a lesser extent by food expiration and excessive amounts of product per package. The majority of respondents indicated that they would be willing to pay extra for a food product packaged in sustainable packaging, also, again regarding willingness to pay extra, consumers preferred certain packaging materials over others. Consumers considered the information on food packaging related to its post-consumer treatment to be unclear, as well as insufficient. Consumers said they find most of this information about the sustainability of packaging from certain sources, mainly from the product packaging itself and from social media. In addition, the parties considered most responsible by respondents for the environmental impacts of food packaging were mainly companies/businesses, followed by end consumers. These statements remarked on consumers' dissatisfaction with companies' commitment to environmental sustainability. However, the fact that respondents also mentioned consumers a great deal highlights how they know they have a shared responsibility for sustainable choices, and this assumption of responsibility is important for developing a circular economic system. In fact, consumers in the questionnaire considered their own contribution in the use and post-consumer treatment of food packaging as very important, and their attention to environmental sustainability has been found to have increased greatly over the past three years.

After examining consumer perspectives, it was decided to also explore the viewpoints of companies in the industry. To achieve this, the survey concluded with an analysis of the Environmental Product Declarations (EPDs) published by companies on the "EPD

International System" platform, the oldest and most significant platform for EPD publication. These declarations are intended for both B2B and B2C audiences. EPDs are voluntary, internationally recognized declarations that are only published after approval by external verification bodies. They provide a thorough, transparent, comparable, and objective communication of a product's environmental impacts throughout its life cycle, based on the Life Cycle Assessment (LCA) methodology. The analysis revealed that EPDs are utilized by a limited number of companies and food packaging types, predominantly within the plastics sector. Moreover, among the EPDs reviewed, only a few emphasized the importance of communication with consumers to enhance their understanding of packaging functions and promote best practices to reduce waste, food loss, and related environmental impacts. This suggests a potential "communication gap" between companies and end consumers.

Conclusion

In conclusion, this research has shown how consumer perceptions, knowledge, levels of responsibility, and interest are critical to the acceptance or rejection of materials, functionalities, and food packaging technologies in general [7]. This complex relationship between consumers and packaging can create barriers to the development of a circular economy [7]. The successes of activities aimed at developing circular organizational models along the supply chain are closely linked to consumer engagement in sustainable practices [5]. In this sense, this paper presented reflections on the importance of deepening research into the development of organisational models aimed at establishing a positive and close relationship between organisations and consumers, in order to achieve positive results in a "win-win" perspective that can benefit all parties involved.

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Assessment and eco-design of reusable packaging: the case of glass water bottles

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Abstract

Reusable packaging is a topic of growing interest due to the possible benefits of environmental sustainability and regulations that drive innovation, such as Packaging and Packaging Waste Regulation (PPWR). The research has focused on reusable glass water bottles in Italy, the leading European country in bottled water consumption. By analyzing Environmental Product Declarations (EPDs) from 3 bottled water brands, two main issues represent a limit for the reuse system sustainability: the scuffing degradation phenomenon that shortens bottle lifespan by degrading mechanical and aesthetic properties and the complex label removal phase during bottle restoration that increases energy consumption. Two eco-design strategies are proposed as answers to the two issues: using the scuffing as a positive feature to improve bottle's attractiveness to consumers, and the implementation of an easily removable label. Both solutions were compared through Life Cycle Assessment (LCA) to the initial scenario, showing the potential for reducing environmental impacts and informing future eco-design improvements for reusable glass bottles.

Keywords: *Reusable packaging; LCA; Water bottles.*

Introduction

The environmental advantage of reusable packaging lies in extending the packaging's useful life, according to the principles of the European Waste Hierarchy [1]. A strong impulse towards a greater diffusion of reusable packaging is coming from the normative level. European policymakers are discussing the introduction of the PPWR [2]. This regulation proposal defines specific targets and modalities regarding the amount of refillable and reusable packaging in use by the different economic sectors. Italy is the leading consumer of bottled water in Europe [3] and the second largest worldwide. Its per capita consumption is more than double that of other European countries and has continuously grown for several years. This is mainly due to a lack of trust in tap water [4] and the success of marketing strategies by bottled water brands [5].

PET single use bottles represent 80% of the total packaged water consumption in Italy [3] while glass accounts for 16.1% of the market, distributed in two ways: one-way glass bottles (VAP) and returnable glass bottles (VAR). Companies are implementing eco-design principles in bottles design mainly by minimizing the weight thanks to geometrical features and by increasing R-PET content.

To understand the different environmental impacts of PET and glass bottles, whether disposable or reusable, the best tool is Life Cycle Assessment (LCA). This objective analysis quantifies the environmental burdens associated with a product's life cycle, identifying and measuring the energy consumed, materials used, and waste released by the system [6].

Methods

Identification of impactful factors

The EPDs of packaged water brands Ferrarelle [7], Cerelia [8], and Levico [9] were analyzed. These studies are based on the third version of the product category rule (PCR) 2010:11 released by EPD International [10] and are, therefore, comparable.

The Functional Unit used in EPD’s is 1 liter of water. Clear and significant relationships between format, material, and use mode emerge from the evaluation of Climate Change (CC) indicator. As shown in Fig1, comparing the values of this indicator it’s clear that: as container capacity increases, the indicator value decreases; one-way glass bottles show significantly higher values for this indicator; PET bottles and returnable glass bottles of similar capacity, although the number of reuse cycles estimated has not been declared by the companies, produce comparable impact values.

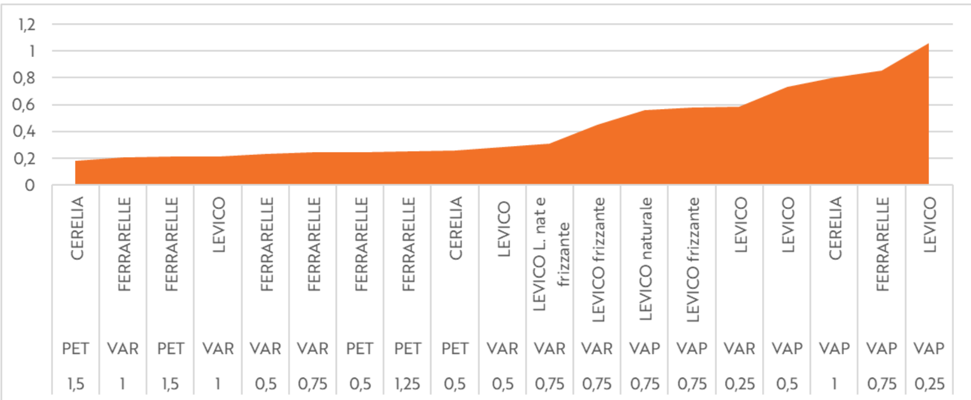

Figure 1. Climate change indicator comparison of bottles of different size, material and mode of use

Through insights from scientific literature and EPD’s analysis, the following factors, common between PET and glass bottles, were identified as contributing to the environmental impacts of packaged water: the materials themselves, based on their characteristics, quantity used, and end-of-life practices; the ratio of packaging mass to the quantity of water transported, favoring larger containers [11] and the distribution phases, where efficiency and distance determine environmental impacts. In the case of VAR bottles, also the number of reuse cycles, distributing impacts over multiple uses and the washing process, requiring energy, water, and chemicals contribute to generate the environmental impacts.

The eco-design actions

The objective of the eco-design actions has been focused on VAR, aiming at maximizing the number of reuses and improving the efficiency of the washing process. As emerged from the confrontation with Ferrarelle, Gruppo Refresco and Berlin Packaging, improving the VAR life cycles involves working on the reasons for their premature discontinuation and, for what concerns the energy efficiency in the washing process, on the label design.

A reason for premature divestment of VAR is caused by the development of scuffing. Scuffing is an ageing process that causes the generation of white marks in areas where bottles come into contact with each other within the bottling lines. This results in surface micro-cracks that, during washing processes in caustic solutions, promote chemical attack on the glass [12]. As reuse cycles progress, this phenomenon becomes increasingly visible, making quality controls more difficult and reducing the perceived value for customers. VAR are removed prematurely from the reuse cycle when scuffing signs, being just an aesthetical damage, become too evident, too early compared to their unexpressed mechanical potentialities.

Regarding the bottle washing process, it has been found through interviews that the label removal process requires an important amount of energy, taking up to 17 minutes to complete a full washing cycle employing high-temperature solutions of hot water, caustic soda and chemicals.

Exploiting the scuffing issue: "Signs of time"

The eco-design strategy proposes to give to the scuffing phenomenon a positive aesthetic value, encouraging the appreciation of the opacities, as long as mechanical performance is guaranteed. To achieve this, one possible approach can be the design of reliefs in the areas where scuffing will occur. When the relief areas of bottles come into contact with each other and undergo various washing cycles, the whitish surface will become increasingly evident. By comparing two bottles with different degrees of scuffing, it is possible to infer which one has been used more times.

Figure 2. An example of design solution that exploit scuffing as an aesthetic element

Reducing the label issue: “Low glue label”

An energy efficient label solution consists in a paper label that completely wraps around the bottle cylinder, ensuring that once the label's diameter is reduced, it adheres completely, using glue only to join the two ends of the paper strip. Label protective shoulders on bottles create two geometric constraints that prevent the label loosening. In this way, the label can be peeled off during washing process in a shorter time and with a reduced energy consumption.

Figure 3. Steps to attach the label to the glass bottle

Findings

Considering a reference scenario, corresponding to the current standard distribution of returnable glass water bottles, two simplified LCA studies have been conducted, considering a partial inventory, derived from secondary data taken from literature. In the first case: “Signs of time”, the number of reuses has been increased, and in the second one, the different label attachment technique has been applied: a larger use of paper versus a minor and localized use of glue, reducing energy consumption during washing process.

The functional unit and system boundaries adopted follow the reference PCR [10]. LCA has been performed on SimaPro 9.5.0.1 (by PRé) software. Processes cut-off datasets are derived from the Ecoinvent database, version 3.9.1. The study has been conducted applying the EF 3.1 calculation method and including the method’s default indicators. Mass of inventory elements has been derived from the inventory data published in the EPD’s of returnable glass bottles distributed by Ferrarelle [7] and Levico [9]. To model other processes, data has been acquired from literature.

Evaluating the "Signs of time” benefits

In the first case scenario, it is possible to evaluate how the possibility of increasing the number of reuse cycles affects environmental impact indicators. As shown by Figure 4, when the number of reuses increases, environmental impacts decrease. Increasing reuse cycles from 10 to 12, would reduce the CC indicator by 5%. This occurs because impacts from production and end-of-life phases are spread across the number of reuse cycles.

Evaluating the "Low glue label" benefits

In this second eco-design intervention, a comparison has been made based on the reduction in energy used in the process and the likely increased label's surface area. The larger the label, the less impactful the intervention is going to be. As shown by Figure 5, with a doubling of the label's mass and considering at the same time a 20% decrease in the washing process energy consumption, this would result in a 0.4% reduction in CC indicator. It is important to consider that even a minimal reduction, in a mass market like bottled water, can determine huge differences in the overall impacts of the sector.

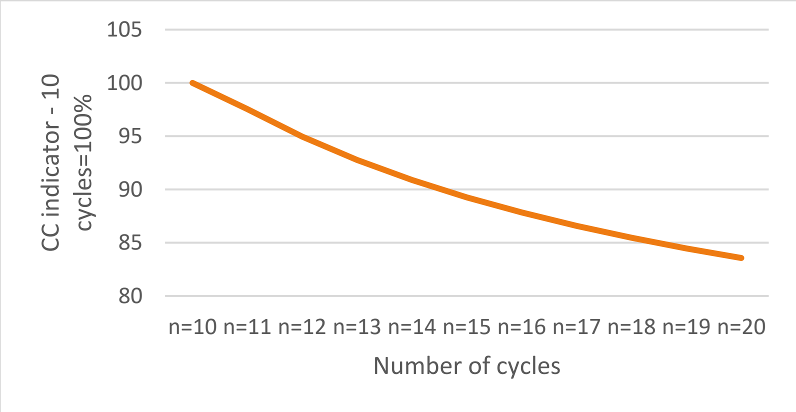

Figure 4. CC indicator variations with increasing number of cycles

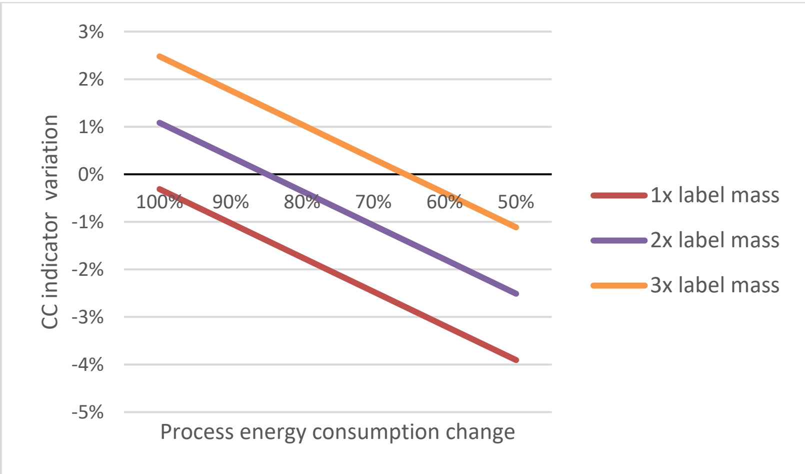

Figure 5. CC indicator variation considering different label masses and energy consumptions

Conclusion

In this work, it has been analyzed the significant scale of bottled water market in Italy. It has been demonstrated an interest of the industry in improving the environmental performances of reusable glass bottles. Based on the confrontation with real industrial cases, scuffing and labeling process have been targeted by eco-design interventions to address environmental concerns. This process has demonstrated the methodological value of LCA applied to design, leading to specific interventions which have results in environmental and product enhancement benefits.

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Technological innovations in the collection and treatment of packaging waste

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Abstract

This study investigates environmental sustainability related to urban waste management and recycling instruments available for cities. In Germany, it was developed the Pfand System, a Deposit Return System (DRS) designed for efficient collection and recycling of packaging. Implemented in 2006, the Pfand System involves consumers paying a deposit on beverages, which is refunded when containers are returned to reverse vending machines [1]. This system has significantly increased the recycling rate of plastic packaging from 47.6% in 2005 to 99.6% in 2019 [2]. The study investigates the correlation between the Pfand System and recycling rates, analyzing variables such as the distribution of reverse vending machines, investments, population, and total plastic packaging consumed [3]. A multiple regression model reveals that increased distribution of vending machines and investments positively impact recycling rates, while population growth and total packaging consumption show negative correlations. The results affirm the system's effectiveness and suggest potential applicability to other countries in order to improve urban waste management and recycling systems.

Keywords: *Circular economy; Packaging; Reverse vending machines; Waste management; Regression.*

Introduction

Germany has earned a reputation as a leader in the environmental sector, highlighting a strong commitment to sustainability and responsible waste management. One of the most distinctive aspects of this environmental philosophy is its advanced approach to recycling. The importance given by German citizens, institutions, and politics to sustainable waste management, particularly of packaging, is a tangible testimony to their commitment to the circular economy [4].

The German recycling system is known for its precision and wide participation of the population. Citizens are usually provided with separate containers for paper, plastic, glass, and organic waste as in any traditional system, but unlike in Italy, they benefit from an extensive system of selective packaging collection known as the Pfand System [5]. The Pfand System, or Deposit Return System (DRS), is a methodology implemented to recollect containers from consumers, either for reuse or recycling. With the addition of a deposit applied to the price paid for the goods in the store, which is refunded when empty bottles or cans are inserted into designated reverse vending machines located at retailer sites, the system has become consolidated and part of German societal habits for many years. Since May 1, 2006, all packaging for beer, mixed drinks, mineral and table waters, and single-use bottles and cans (PET and glass) are subject to a deposit. To ensure the system is well implemented and regulated, the DPG (Deutsche Pfandsystem GmbH) was founded in 2005, an initiative of the German retail sector and the beverage industry [6]. This organization provides the legal framework that regulates and organizes everything concerning the deposit system and the companies involved in it. The DPG has established regulations for a unified labeling system, which allows the automation of deposit beverage containers [7]. Focusing on the recycling rate of packaging in Germany, one can notice the exponential growth that has occurred since the new system's approval. Particularly focusing on the sector of plastic packaging, the recycling rate increased from 47.60% in 2005 to 99.60% of plastic packaging recycled in Germany in 2019 [8]. In light of these results, it was decided to investigate "if and how much" this growth in material recycling is correlated to the introduction of the new system, in order to understand its effects, benefits, and potential applicability to the Italian model.

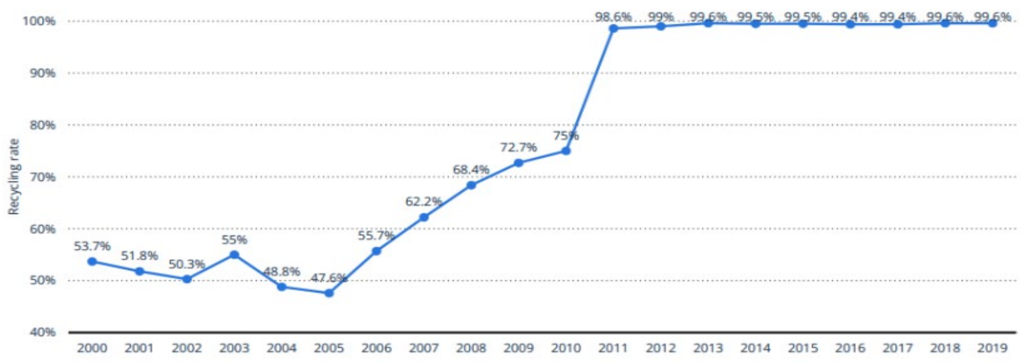

Figure 1. Recycling rate for plastic packaging in Germany from 2000 to 2019 (**Source**: Statistics report on the packaging industry in Germany, 2024, p.30; GVM-Gesellschaft für Verpackungsmarktforschung).

Methods

This paragraph aims to explain the validity of the Pfand system through the study of the variables that impact the recovery and recycling rate of plastic packaging introduced for consumption in Germany. The study period considered is from 2006, the year in which the Pfand system was implemented across Germany, to 2020. The variables considered in this paragraph are the result of a broader dataset of variables that, during the in-depth study of the subject, were discarded due to a lack of fundamental connections or due to statistical application issues (i.e., multicollinearity). The process of filtering the variables from the original dataset resulted in a small sample of variables with good fundamental validity. Specifically, the variables analyzed are as follows:

- **Distribution of Reverse Vending Machines**: This variable accounts for the distribution of eco-compactors that issue deposit receipts in Germany over the years.
- **Investments**: This variable considers the cost of purchasing and installing the Reverse Vending Machines.
- Population
- **Total Plastic Packaging Consumed**: This variable refers to the total amount of plastic packaging of any kind introduced for consumption in Germany.
- **Total Plastic Packaging Recycled**: This variable refers to the recycling rate of "Total Plastic Packaging Consumed".

Table 1. Time series of the variable used (Source: GVM-Gesellschaft für Verpackungsmarktforschung; DPG-Deutsche Pfandsystem GmbH).

Years	(RVM)	Investments (€)	Population	total plastic packaging consumed	Total Plastic Recycled Packaging
2006	8800	110.000.000€	82.380.000	2.591.200 T	1.443.298 T
2007	8930	117.304.480€	82.270.000	2.643.700 T	1.644.381 T
2008	9599	127.090.760€	82.110.000	2.732.300 T	1.868.893 T
2009	9771	131.126.820€	81.900.000	2.620.700 T	1.905.248 T
2010	11237	151.901.766€	81.780.000	2.690.000 T	2.017.500 T
2011	13148	178.418.360€	80.127.000	2.775.700 T	2.736.840 T
2012	15646	213.100.154€	80.430.000	2.836.600 T	2.808.234 T
2013	18932	258.608.459€	80.650.000	2.873.200 T	2.858.834 T
2014	23286	318.554.127€	80.980.000	2.945.500 T	2.930.772 T
2015	25149	344.616.884€	81.690.000	3.052.100 T	3.036.839 T
2016	26658	366.760.084€	82.350.000	3.097.600 T	2.911.744 T
2017	28791	398.260.185€	82.660.000	3.184.800 T	2.993.712 T
2018	32245	447.889.398€	82.910.000	3.235.700 T	3.106.272 T
2019	40210	556.507.576€	83.090.000	3.180.100 T	3.052.896 T
2020	51067	705.028.350€	83.160.000	3.147.376 T	3.064.329 T

Once all the variables are explained, we proceed to create a regression model that aims to explain how the use of the Pfand system in Germany has led to an increase in the recycling rate for plastic packaging. The multiple regression equation has the general formula:

Y=β0+β1X1+β2X2+β3X3+βnXn+ϵ

Where the dependent variable Y represents the recycled plastic packaging, β0 is the intercept or constant term while the independent variables are the following: X1 is RVM distribution; X2 is the population; X3 represents investments; X4 is the total plastic packaging consumed. β1, β2, β3, β4 are the regression coefficients for each independent variable and ϵ is the residual error that is the difference between the observed values and the values predicted by a statistical model.

To implement the model using STATA software, it was necessary to standardize the variables to make them more comparable to each other.

Findings

The results of the regression model provide statistical evidence supporting the Pfand system in Germany, which has undoubtedly brought significant benefits to the recycling rate of plastic packaging. Below is the output of the statistical model.

Table 2. Multiple regression from 2006 to 2020

Total Plastic Recycled Packaging	Coefficient	Std. Err.	t	P>|t|	95% Conf. Interval	
total plastic packaging consumed	2.019.939	0.1778654	11.36	0.000	16.236	2.416.247
distribution RVM	2.798.206	2.798.206	2.54	0.029	31.54	5.251.012
Investments	0.021099	0.0079771	2.64	0.025	0.0033249	0.038873
Population	-0.3255198	0.0172803	-19	0.000	-0,364022	-0,28702
_cons	2.32e+07	1456817	15.89	0.000	1.99e+07	-2,64E+07

Table 3. General data of the multiple regression model (Source: Personal elaboration)

Number of obs = 15
F(4, 10) = 463.33
Prob > F = 0.0000

R-squared = 0.9946
Adj R-squared = 0.9925
Root MSE = 51433

Proceeding finally to a normalization of the results by referencing the coefficients of the standardized variables, the results can be explained as follows:

- **Total Plastic Packaging Consumed**: An increase of one ton in the total plastic packaging consumed is associated with a decrease of approximately 0.05619965 tons in the total plastic packaging recycled, holding other variables constant.
- **RVM Distribution**: An increase of one unit in the distribution of RVM is associated with an increase of approximately 54.55602 tons in the total plastic packaging recycled, holding other variables constant.
- **Investments**: An increase of one unit in investments is associated with an increase of approximately 0.003766976 tons in the total plastic packaging recycled, holding other variables constant.
- **Population**: An increase of one unit in the population is associated with a decrease of approximately 3.24332 tons in the total plastic packaging recycled, holding other variables constant.

Conclusion

The implementation of the Pfand System in Germany has proven highly effective in enhancing the recycling rate of plastic packaging, increasing it from 47.6% in 2005 to 99.6% in 2019. The multiple regression analysis demonstrates that the distribution of reverse vending machines and investments in the system significantly contribute to higher recycling rates. Conversely, population growth and total plastic packaging consumption show negative correlations. While the study confirms the substantial benefits of the Pfand System, it suggests that a comprehensive Life Cycle Assessment (LCA) is necessary to fully evaluate the environmental impact, including the production of reverse vending machines [9]. Overall, this research highlights the success of Germany's recycling model and its potential as a benchmark for other nations. This study aims to be an initial approach to understanding more in detail the potential benefits derived from new recycling models, looking at nations that excel in the recycling sector to evaluate the conditions for applying these models in Italy, thereby improving current and future performance.

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Packaging as a virtuous tool for conveying sustainability in the agri-food sector : empirical analysis of business case studies

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Abstract
This paper aims to analyse the relationship between the topic of food packaging and sustainability. Starting from a general overview of these issues in the current context, this research conducts a thorough review of the scientific literature. Furthermore, it describes and analyses some case studies in order to provide empirical evidence to the research. In particular, eight companies from different food-sectors were interviewed with the aim of conducting a cross-sectional comparison on their packaging-related decisions. In conclusion, the analysis carried out has revealed the strong strategic potential of packaging as a tool capable of telling, through its essence, the quality of the product it contains and the values of the company from which it originates. Moreover, it shows that the level of maturity of a sustainable package is not only evident from its green and eco-friendly characteristics, but also from the ethical and social responsibility requirements it meets.

Keywords: *Food packaging; Sustainable development; Eco-design; Qualitative interviews.*

Introduction
Sustainability has long been at the centre of the European economic recovery policies and, recently, in the face of greater citizen awareness, efforts are aimed at making the entire food system less environmentally impactful. In this context, packaging plays a key role in the green transition of the food industries, which are increasingly committed to more sustainable development.

Methods
The study was divided into three stages: a general framework of these issues in the current context, a review of the available scientific literature, and, in conclusion, the empirical research.

Food packaging and sustainability
Packaging, a synthesis of functional and communicative functions [1], has always played a central role in the food system and attracts the attention of many authors and researchers, as well as public and private institutions. It is a controversial object:

essential as it interacts with contents that are indispensable for human survival, but also omissible since it represents one of the main causes of environmental pollution [2].

The potential of packaging – literature review

From the analysis of the existing scientific literature, three thematic clusters were identified, one for each declination of sustainability:

- The first deals with the complexity and multi-functionality of food packaging which, in order to ensure its primary function while respecting sustainability standards, requires the coordinated collaboration of numerous actors along the supply chain [3, 4].
- The second cluster is concerned with the efforts and interventions aimed at reducing the ecological impact of packaging, especially plastic packaging [5, 6].
- The last cluster frames food packaging as an informative resource and point of contact with the consumer [7, 8].

Empirical research

The research was carried out on two levels: desk research aimed at better contextualizing each case study through the consultation of secondary sources and subsequently a field analysis, based on personal interviews with figures within the business realities.

Business cases

The companies under analysis (Figure 1) were eight - four of them based in Veneto - and they are mostly food industries, with the only exception of one operating in wholesale trade (ATECO Code 46).

Company	ATECO Code	Head office	Turnover in millions of euro (2021)	Sustainability Report	Interviewed figures
Arbi Dario	10.2	PT	56,88	No	Alessandro Arbi (CEO)
L'Insalata dell'Orto	10.3	VE	39,27	Yes	Sara Menin (CMO)
Oleificio Zucchi	10.4	CR	265,43	Yes	Andrea Fontanella (COO)
Caseificio Tomasoni	10.5	TV	11,23	No	Eva Tomasoni (CMO)
Poggio del Farro	10.6	FI	11,40	No	Federico Galeotti (CEO)
Il Mangiar Sano	10.72	TV	23,56	No	Elena Arpegaro (CMO)
Sgambaro	10.73	TV	22,19	No	Martina Durighello (CMO)
Fileni alimentare	46.32	MC	408,66	Yes	Marco Gava (PR & SMM)

Figure 1. Interviewed companies

Cross-case analysis

To organise the information that emerged from the personal testimonies of the interviewees, a coding activity was carried out following the so-called Gioia Method [9], which allows to limit the interference of a subjective nature in the interpretation of the data, bringing greater qualitative rigor to the analysis. This is a graphical representation that reports the direct quotes of the interviewed subjects (1st Order Concepts) grouped into 2nd Order Themes and finally into an Aggregate Dimension that allows to reconnect to the topics that previously emerged from the literature analysis.
The Dimensions I identified are four: the first (Figure 2) - represented below as an example – is concerned the general approach and attitude of the selected companies, while the others are focused on packaging and the link that relates it to the three declinations of sustainability: economic, environmental and social.

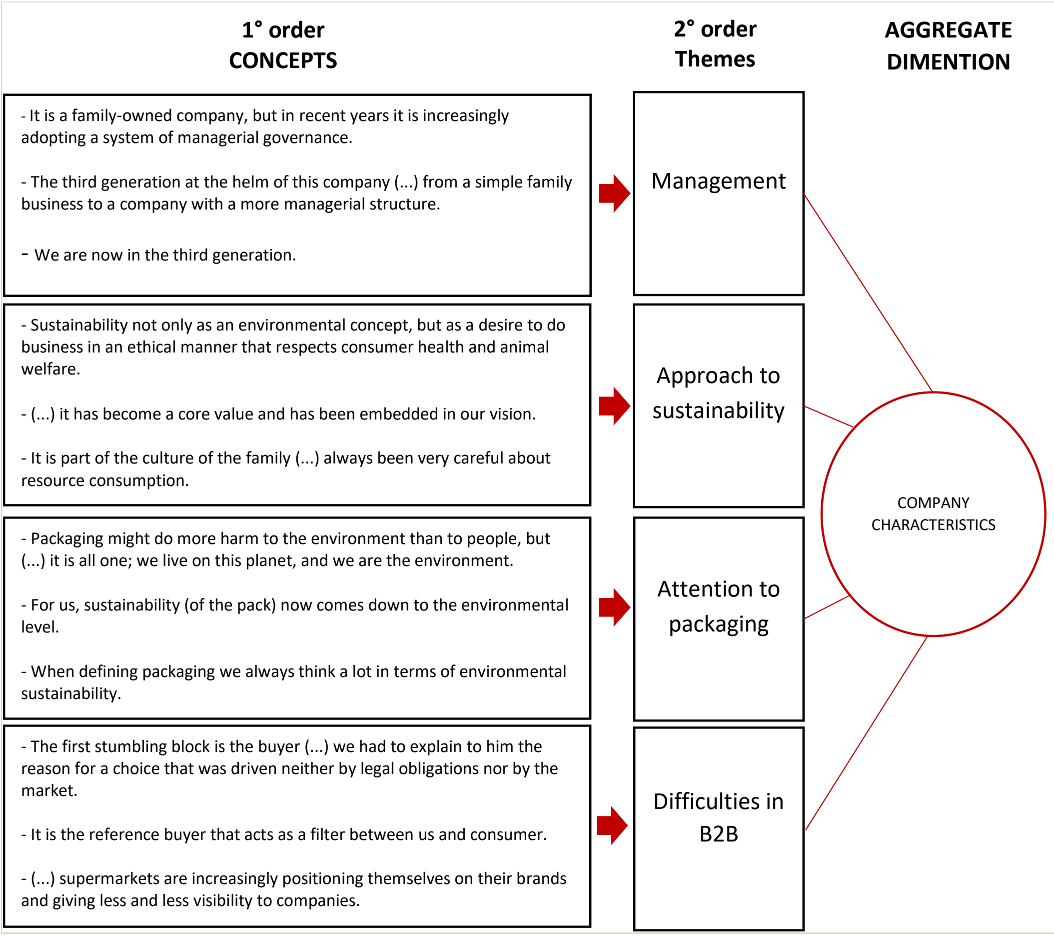

Figure 2. Business features

Findings

By relating the three sustainability dimensions of packaging and integrating them with the attitudinal approach of the interviewed companies, we can outline some important insights.

- Firstly, we can affirm that the recent institutions and citizens' increase awareness has also influenced the actions of companies, which are now supporting significant investments in more sustainable packaging choices [10]. Among the motivations driving companies in this direction, besides the need to adapt to regulatory and market requirements, the values and business philosophy stand out. Indeed, five out of the eight interviewees maintain that the main driver is the cultural one, completing a broader Mission that cares for the well-being of the planet and people. Furthermore, to confirm that the collaboration of all stakeholders is necessary for a faster transition towards a responsible production and consumption model, we find their direct testimonies: for their innovations, companies have collaborated with various packaging manufacturers, but also with universities and research centres. Among the important players along the supply chain, supermarkets are also distinguished [11]. Retailers, in fact, play an active role in the implementation of higher sustainability standards, particularly in influencing the behaviours of their partners.

- The environmental aspect is undoubtedly the one on which companies focus the most. Both from the literature review and the empirical analysis, it has been observed that the attention is primarily directed towards the materials and composition of the packaging, particularly observing an increasingly strong reduction in the use of plastic in favour of other materials considered less impactful [12]. Four out of the eight interviewed companies have recently introduced the restyling of some products, moving from the use of plastic materials to cellulose-based or biopolymer materials with biodegradable and/or compostable characteristics. Despite this trend, plastic still holds the primacy and - when its replacement is not possible - companies are committed to a more circular management: a reduction in the quantity used and, above all, the use of materials that are 100% recyclable and sometimes even from recycled sources (r-PET).
- The social sustainability of packaging, lastly, is expressed in the figure of the consumer, the recipient and interpreter of the packaging as a tool for communication, information and education [13]. The packaging, in fact, can convey values and raise awareness towards the adoption of more responsible behaviours. In this sense, the packaging also becomes ethical and represents a valid means to reflect on socio-environmental issues, such as food well-being, traceability and territoriality. These are topics that have been extensively addressed by the interviewed companies, which try to tell the characteristics of their product, its history and its nutritional qualities through the packaging. To do this, in addition to the visual and verbal language, companies increasingly use digital tools [14], such as the QR-code, which allows to extend communication to online content, thus overcoming the dimensional constraint of the packaging.

Discussion/Conclusion

An interesting topic that emerged from the empirical analysis concerns the hypothetical existence of a causal link between the offer of organic products and the adoption of sustainable packaging. This is an interesting concept, worthy of further investigation, and can represent a stimulating starting point for possible future research. Another significant input concerns the disposal system for compostable waste. In particular, two of the interviewees have pointed out how Italy lacks adequate plants for the management of compostable waste, highlighting the presence of some technological constraints at the end of the useful life of the packaging. These constraints, however, would require upstream interventions.

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Sustainable packaging innovations and supply chain interactions: theoretical considerations and empirical evidence

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Abstract

This study examines sustainable packaging innovation by considering the entire packaging supply chain. The aim is to understand the importance of interactions between the various actors in the supply chain and to analyse the main actions undertaken by them to create low environmental impact packaging. The authors pursued the objective by first conducting a theoretical analysis, through a literature review that presents the main defining aspects and focuses on the interactions and actions undertaken by the actors in the packaging production chain, and then by developing an empirical study, using data published by the World Packaging Organization. The results of this study reveal an increase in awareness of the dangers of the packaging industry, highlighting the importance of sustainable packaging innovations. Achieving effective sustainable packaging innovations requires strong interaction between the actors in the packaging supply chain, and recycling and reduction practices are valid tools in which they can invest.

Keywords: *Packaging; Environmental; Sustainable; Waste; interaction.*

Introduction

Packaging has acquired a fundamental role in daily life, and the demand for packaging appears to be constantly increasing. However, in recent years, global concern for environmental protection has grown and an extensive literature has discussed the environmental impact of packaging [1]. Packaging is recognized as a major contributor to environmental pollution due to emissions from the packaging industry into air and water, due to its significant role in resource depletion [2] and due to the related excessive consumption of water and energy [3]. Furthermore, although they are often made of resistant materials, packaging has high volumes and a relatively short life cycle; therefore, it quickly becomes waste once its immediate functions are exhausted [4]. Companies, consumers and institutions are now focusing on eco-friendly packaging, driving innovations to make packaging production and consumption processes more sustainable. This study analyses innovations in sustainable packaging from a perspective that considers the entire packaging supply chain [5][6]. It focuses on the various actors involved, exploring their needs, skills and the dynamics of their relationships. The aim is to understand how these actors contribute through concrete actions to the sustainability of packaging, complementing existing research that identifies packaging as an integrated system managed by numerous participants throughout its life cycle.

The literature review reveals that each actor in the packaging supply chain has specific roles and responsibilities, which are crucial for the development of sustainable packaging innovations. It is essential that partners collaborate from the initial phase of the project, evaluating the entire packaging system [7]. The literature highlights various forms of interaction and collaboration between the actors involved, who need to exchange information and adapt to each other's needs to optimize the overall system. The study aims to understand the importance of interdisciplinary approaches and interactions between actors in the realization of eco-friendly packaging, exploring the most effective practices adopted by them. Therefore, the study asks the following research questions:

RQ1: Which are the main interactions in the supply chain for the implementation of sustainable packaging innovations? How do they work?

RQ2: What specific practices do packaging companies implement, with the participation and assistance of other actors in the production chain, to reduce the environmental impact of packaging and make it innovative and sustainable?

These research questions aim to deepen the existing literature on sustainable packaging, analyzing it from the perspective of supply chain; furthermore, they search for an empirical validation of the points that have been mentioned above.

Methods

To pursue the objectives of this study, after an international literature review, we conducted an empirical investigation, employing three different types of statistical analyses using R-studio on a database specifically built from data published by the World Packaging Organization (WPO). Since 1970, every year this organization organizes an international competition, the World Star Competition, which awards the best packaging innovations presented by various entities (belonging to the packaging industry) from over 34 countries around the world. For the construction of the database, the author considered 840 types of packaging that received one or more World Star awards from 2020 to 2023. For each awarded example of packaging the database specifies the following informations, in accordance with the literature review:

- the type of award received (either for the packaging category and/or special awards for sustainability, marketing, accessibility, food-saving packaging).

- the actions taken to make the packaging innovative and sustainable, such as reducing the use of resources and making packaging materials lighter (reduction), using materials that can be reused over time (reuse), preparing the packaging for recycling or using recycled materials (recycling), optimising logistics processes and improving production processes.

- whether, during the development of the packaging, there is interaction between various actors in the packaging supply chain, including sustainability certifications, public policies, interactions between different types of companies, collaboration between companies and universities/research centres, interactions with consumers (e.g. environmental labelling, involvement in the creation), interactions for the disposal phase of the packaging and collaboration with design consultants.

- whether these actions have led to a reduction in CO_2/other pollutant emissions and have saved water and energy during the production/transportation of the packaging.

First, the authors conducted a series of cross-frequency analyses, for example between the country of origin of the packaging and the type of premium.

Secondly, two multiple linear regression models were developed. In both models, the dataset column related to the actual reduction of CO_2/other emissions and water/energy consumption in packaging production (achieved through actions implemented by stakeholders) is the dependent variable. The first model uses seven types of possible interactions between different actors in the packaging supply chain as independent variables: sustainability certifications, public policies, interactions between different types of companies, interaction between companies and universities/research centers, interaction between companies and consumers, interaction between actors for the packaging disposal phase, and collaboration between companies and design consultants. This allows us to understand how these forms of interaction can influence consumption and emission reduction and therefore have an impact on the sustainable development of packaging. The second model aims to understand the relationship between the above-mentioned dependent variable and five independent variables (reduce, reuse, recycle, logistics process optimization, production process optimization), which represent concrete actions undertaken by various actors to reduce emissions and consumption in packaging production. Finally, a text mining analysis was performed on the description of each packaging in the database. After data cleaning, the most recurrent words were identified and a sentiment analysis of the text data was conducted.

Findings

By The authors used the results of the cross-frequency analyses to gain an overview of the current state of sustainable packaging innovations worldwide. These analyses show that, from 2020 to 2023, Japan is the country from which most companies are rewarded for introducing packaging innovations. Furthermore, Australia and New Zealand are the countries with the highest number of companies engaged in sustainable packaging and waste reduction efforts. To answer RQ1, the results of the first regression model are useful. Starting from this model, it is possible to understand which of the various regressors has the greatest impact on the dependent variable (it is the one with the highest coefficient) and the type of relationship (positive or negative) that links the independent variables to the dependent one (this depends on the sign of the coefficient). In the last step of the model, only the independent variables that have the highest explanatory power are retained. In fact, there are 4 visible variables and they are "Environmental sustainability certifications", "Interactions with institutions, i.e. public policies", "Collaboration between companies and universities/research centers", "Collaboration between companies and design consultants". The first three types of interactions (environmental sustainability certifications; Interactions with institutions, i.e. public policies; collaboration between companies and universities/research centers) show a positive relationship with the reduction of emissions/consumption in the packaging sector (the coefficients have a positive sign), thus positively influencing the development of sustainable packaging. However, collaboration between companies and designers (which instead has a negative coefficient) seems to have a negative influence on emissions and consumption reduction.

```
Residual standard error: 0.3495 on 835 degrees of freedom
Multiple R-squared:  0.02828,   Adjusted R-squared:  0.02362
F-statistic: 6.074 on 4 and 835 DF,  p-value: 8.063e-05
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Figure 1. Overall p-value and adjusted R-squared of reg model 1 (R-studio). *Source: Authors' elaboration.*

To answer RQ2, the authors used the second multiple linear regression model which follows the same structure and logic as the first. This model presents a positive relationship between the actions actually implemented by the actors in the supply chain and the reduction of emissions and consumption in the packaging industry. The actions that have the greatest positive impact on the reduction of CO_2 emissions and energy and water consumption in the packaging industry (and therefore that have the greatest impact on the production of sustainable packaging) are Reduce and Recycle.

Finally, a text mining analysis was conducted on the text column of the dataset related to the winning packaging product description, which meticulously outlines the winning packaging type. After cleaning the text data by removing commonly used terms, conjunctions, and spaces, the most frequently occurring words in the database were identified. Efforts were made to identify the most frequently occurring words in the database. The most recurring words refer to the materials used, the theme of "waste" and the concrete actions implemented. Additionally, the text data was classified to understand its tone: sentiment analysis revealed a positive tone; the sentiment that shines through is "trust".

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Residual standard error: 0.3442 on 837 degrees of freedom
Multiple R-squared:  0.05576,   Adjusted R-squared:  0.05351
F-statistic: 24.71 on 2 and 837 DF,  p-value: 3.729e-11
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Figure 2. Overall p-value and adjusted R-squared of reg model 1 (R-studio). *Source: Authors' elaboration.*

Conclusion

This study highlights that concerns about the negative impacts of the packaging industry have grown significantly in recent years; this is a consequence of increased global awareness about the environment. A key finding is that interaction between various stakeholders in the supply chain is crucial to implement sustainable packaging innovations. To be considered innovative and sustainable, packaging has to satisfy a set of complex requirements, which require the active involvement of all actors along the packaging supply chain to foster effective collaborations. Actions taken by packaging manufacturers, together with other stakeholders in the industry, play a key role in reducing the environmental impact of packaging and making it more sustainable, with a particular focus on Reduce and Recycle practices. Although this study provides original insights into sustainable packaging innovation, it has some limitations. The database used focuses exclusively on WorldStar Competition-winning packaging, which may not fully represent the diversity of this sector. Future studies could benefit from a larger sample size to drive towards more robust results. Furthermore, the multiple linear regression models used in this study demonstrate limited adequacy (adjusted R-square of 0.02362 and 0.05351; they are highlighted in *Figure 1* and *Figure 2*), suggesting caution in the statistical interpretation of the results (this is because the model fit is optimal if the adjusted R-squared is close to 1). The empirical investigation highlights the importance of promoting synergies between all stakeholders in the packaging supply chain to address current environmental challenges. Investing in established practices such as reduction and recycling remains key to progressing towards more sustainable packaging.

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SUSTAINABILITY AND CIRCULARITY

Sibylline Plots – Stories Connections Knowledge

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Abstract

The project stems from a reflection on the cultural, environmental, and social richness of small Italian municipalities. These places are mostly located in high hill and mountain areas and are often isolated and abandoned by their own inhabitants, administrations, and tourism. Among these, we find the territories of the Apennine hinterland. The thesis aims to be a catalyst for attention on the Monti Sibillini National Park and its surrounding areas. The systemic project aims to serve as an informational base on the theme of ancient knowledge, considered one of the peculiarities to be valorized of the socalled montanità culturale[2] of the territory. The intention is also to valorize productions that have been partly forgotten and that pay strong attention to the use of resources, material recovery, and circularity. The project includes an editorial collection of the voices of artisans, the distribution of posters in the territory, and the creation of objects available in artisan workshops.

Keywords: *Tourism; Sustainability; Craftmanship; Circularity; Ancient knowledge.*

Introduction

The thesis research is dedicated to the mountainous villages and territories of the *Appennino umbro-marchigiano*[3] . These areas are fascinatingly controversial: subject to depopulation, sometimes abandoned by administrations and residents, yet rich in history, culture, and traditions. "The cultural richness in the Central Apennines is also due to the ancient presence, since the late Middle Ages, of a multitude of trade routes connecting central Italy to the northern coast, from the ports of Ancona, Fano, and Pesaro reaching Venice, inland towards Abruzzo and Lazio with mule tracks and paths traced by transhumance and merchants" [1]. From the beginning of industrial development until today, these territories have experienced a decline in productivity and population, in addition to the challenges posed by natural phenomena such as earthquakes. "They are considered fragile territories, but at the same time they certainly maintain strengths for new enhancement paths starting from their uniqueness and fragility" [2]. To outline the project's setting, it is useful to use the term *montagna di mezzo*[4] , as it effectively introduces the Apennine landscape, "a marginal mountain, distant from the splendor and impacts of alpine tourism economy" [3]. Indeed, this definition evokes an idea of a mountain that deviates from the collective imagery of

[2] Cultural montanity, [EN]
[3] *Umbria - Marche Apennines*, a segment of the Italian mountain range crossing the regions of Umbria and Marche.
[4] Middle mountain, [EN

majestic peaks and gentle valleys hosting charming villages where people not only integrate into the natural way of life but also develop a tourist evolution process throughout almost every season of the year. In the Alps, the preservation and dissemination of mountain culture thrive due to the interwoven network that has evolved over time among administrations, residents, tourism, and the landscape. This culture resides in the middle mountains and for this reason must be rediscovered through enhancement processes aimed at bringing to light the peculiarities, stories, and values of the place. All of this while respecting and accommodating the characteristic slow pace of the Apennine territories, a rhythm that is found in the daily life of the mountains: following the flow of time in harmony with nature, lengthening the paths to reach inhabited centers, slowing down in small daily actions. When referring to the slow pace, it is necessary to include, in addition to dwelling, also the act of visiting: hence we mention sustainable tourism, which can only be considered such if "conceived, realized, and managed in a way that does not generate phenomena of social and economic, inequality, especially to the detriment of the populations of the regions hosting the tourism itself" [4].

During the preliminary approach to the project and following the research carried out on the cultural and traditional riches of the territory, I decided to focus my attention on the field of ancient artisanal knowledge, which can be considered a bridge between the old and new generations of the territory. Nowadays, the return to or permanence in the Apennine lands possesses a "renewed attractiveness, which can be read in the personal stories of returnees, in the tales of emotions of mountain people by choice, immigrants, and young people who have made work and life bets on the bond with the territory" [5]. Analyzing artisanal activities is also interesting from the perspective of technological development, observing how a synergy has been created between ancient methods and new advancements, projecting production towards an increasingly sustainable perspective. By retaining what was good in the past for better future prospects, new forms of circular economy focus on the regeneration of ecosystem services. In fact, the experiences of current artisans "rediscover traditional resources while innovating them" [6]. Today, much is said about "experiential tourism" related to craftsmanship. Its success is probably dictated on one hand by the need for hands-on experience, which appeals to our spontaneous instincts for manual work and curbs, even if only for a few hours, the progressive laziness of our senses, dulled by the high degree of digital usage in everyday life, and on the other hand, it could be synonymous with a desire not to lose origins and traditions. This approach proves effective only when the experience is preceded by cultural and historical insight into the various activities to be evoked and by a commitment to protecting workshops and artisanal knowledge. Pursuing the quest for authenticity from a solely "ostentatious" and "staged" perspective [7] risks creating theatrical, culturally insignificant situations. Only with an approach that takes into account the aspects described above is it possible to give a firm restart to the identity and image of a territory. This is why my research considers historical and economic insights into the Apennines and takes into consideration, as sources, not only ordinary texts but also the stories and legends that were narrated in front of domestic hearths. The stories orally transmitted from elders to young people preserve the values, morals, and knowledge that they wanted to pass on to new generations. The dominant story is that of Queen Sibylla, from whom the Monti Sibillini National Park derives its name, a protected area of the *Umbria - Marche Apennines*. The events narrated in these stories, besides opening up an interesting imagery about the figure of the Sibylla, her fairies, and their underground world, are strongly linked to the history of the inhabitants of the area, resurfacing in daily life in various aspects: recreational, literary, and productive.

Methods

It's essential to clarify the actual role of communication design in this territorial enhancement project. Following preliminary historical and cultural research, a communication strategy study enables the redefinition of the territory's identity. Furthermore, the communication project can create networks for exchange, dissemination, and knowledge where they are lacking and strengthen them where they are weak. These networks connect individual villages, activities, and people, traversed by tourists opting for sustainable and slow-paced visits. Additionally, effective graphic and communication choices can engage various user targets, including young and elderly residents, tourists, and slow travelers in less-visited areas, even attracting those unfamiliar with these places.

Survey and Material Collection

The applied research methodology involved interviews with three young resident artisans with productive activities in the *Appennino umbro-marchigiano* and a historical expert of the area. These are semi-structured interviews with various focuses: outlining the craft activity over time and space (its history and relationship with the territory), identifying the tools and practices inherited from the ancient trade and the aspects of sustainability that are still present, and exploring the relationship between the craft and the local inhabitants as well as tourism. During the visits to the various activities in addition to conducting interviews, a photographic reportage was created to enrich the editorial project. The photographs vary in nature, including landscapes of the Monti Sibillini and the relevant locations, as well as descriptive images of the trades (tools, raw materials, work processes).Additionally, significant quotes from the interviews were included in a series of posters to communicate the project.

Figure 1. The editorial project "Voices of the Artisans"

Figure 2: Pages from the editorial project “Voices of the Artisans”

Figure 3. Posters

Findings

Communication development primarily focuses on offline consumption through exposed communication artifacts, an editorial project, and a collection of buttons delivered with purchases from the workshops. The project's approach starts with viewing the posters indicating the presence of the workshops. Upon visiting the workshops, one can access the editorial project "Voices of the Artisans", featuring photographs and interviews to deepen understanding of artisanal work. Furthermore, with the purchase of a workshop product, the packaging includes a reusable button. The choice of offline consumption is tied to the need to create real and physical connections immediately with the environment and culture of the territory, accessible to anyone present there, whether by chance or residence.

Discussion/Conclusion

Through the development of effective communication, the project succeeds in bringing a wide audience closer to the knowledge of ancient crafts and traditions, making activities perceived as outdated by the collective imagination captivating. Information regarding ancient craft activities is emphasized from a user "education" perspective, focusing not only on artisanal technicalities but also on cultural, environmental, and social sustainability aspects. In the future, the project could expand both in terms of the topics covered and the means of communication, considering online design as well.

This would not only serve as an immediate system for those present in the area but also act as a stimulus for specially organized visits to the Apennine territories, following exposure to the project through social media channels and websites. The use of digital platforms should not replace the experience but rather enhance it by publishing multimedia materials and increasing user engagement.

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Assessing circular economy scenarios in the washing machine sector: a statistical analysis

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Abstract

Circular Economy (CE) is the new paradigm able to overcome the traditional linear system limitations, by decoupling economic and social growth from resource consumption and waste generation. In this context, the Washing Machine (WM) industry results as a promising sector to intervene due to its high resource demand and the unexploited economic opportunities of closing the loop. This paper analyses the European WM sector context by assessing CE scenarios with a statistical approach. By comparing three CE scenarios against a linear economy baseline, this research presents the environmental, economic and social impacts of WM lifespan extension, pay-per-wash business models, and WM refurbishment. The paper shows the absence of a single win-win-win scenario, but each one has improving aspects. This may lead to future research exploration of the win-win-win combination of circular strategies. Moreover, the use phase is confirmed as the most influential, introducing the need of users behaviour policies.

Keywords: *Tourism; Sustainability; Craftmanship; Circularity; Ancient knowledge.*

Introduction

The Circular Economy (CE) is considered as the new economic paradigm able to overcome the environmental, industrial, and social issues of the Linear Economy. Indeed, CE contributes to sustainable production and consumption by decoupling economic growth from resource use and waste generation [1]. Benefits can be signed up at different levels: (i) environmental, in terms of reducing in emissions, enhancing soil and biodiversity, and conserving resources; (ii) social, in terms of improving the life quality; and (iii) economic, in terms of reducing raw material costs and increasing new business opportunities [7;6]. The circular transition requires also the implementation of different strategies [10] such as reducing, product redesign, rethinking business models and reconfiguring supply chains to collect end-of-life products for secondary raw materials [9]. Companies are therefore called upon to apply some levers of action, i.e. tools and practices to implement a circular business, which can be enabled by several facilitating factors, including the new digital technologies underpinning Industry 4.0, the active role of end consumers and institutional legislative drivers [8]. According to previous studies, at European level, the Electrical and Electronic Equipment (EEE) industry, and in particular the white goods sector, is one of the most promising areas for intervention due to the products' life cycle high impacts. In this context, the Washing Machine (WM) can be considered as a valid product to assess environmental impacts and to test methods for their evaluation, as it accounts for about one-fifth impacts of the household appliances in use [4]. In 2019, 27,7 billion of units were sold in Europe [3], including an elevated demand of raw materials such as steel, plastics, aluminum, and other critical raw materials for the production phase [5]. Nevertheless, the use phase is shown as the most economically and environmentally impactful phase of the WM [1] due to energy and water consumption. Finally, the end-of-life stage is not negligible too, since only 35% of discarded volumes are collected and recycled in Europe [2]. Therefore, this paper aims to assess the environmental, economic, and social impacts conducted on the WM industry in European countries (EU28), comparing three different CE business models against the traditional linear system baseline. It is also proposed to carry out a critical analysis to highlight the benefits, the criticalities and the most influential factors of each scenario.

Methods

Literature review

A systematic review of scientific literature has been conducted to identify the possible gaps in the scientific background yet to be investigated. A series of scientific articles have been selected according to the combination of keywords associated to the CE, 4R strategies, the EEE and its waste stream, or the service-based business models topics. A total of 19 documents were collected, of which only three refer to non-European studies. Discriminating factors for the analysis include the scope and a specific product category, the study methodology (i.e., Life Cycle Assessment, Life Cycle Costing, or others) and the investigated impacts (environmental, economic, and social). The period from 2017 to 2021 has been considered as the reference period. Finally, gaps have been observed in the absence of a comprehensive study of all sustainability impact categories (environmental, social, and economic), and in the absence of a simplified tool to assess Circular Economy impacts on a large scale.

The Framework and the Simulation tool

To fill the gaps, this paper proposes a systemic framework to support the simplified evaluation of CE scenarios. The framework has been developed from preliminary research by Bressanelli et al. [8;9], and is considered as a valid and comprehensive alternative analytical model, specifically built for durable goods and validated on case studies. The main potential of this model lies in its ability to deliver results at micro and macro sectoral levels, as well as at environmental, social, and economic levels simultaneously, by combining a set of circular levers and enabling factors, as building blocks of Circular Scenarios. To enable the simultaneous stochastic simulation of scenarios and statistical representation of the related impacts, the initial version of the framework and the resulting simulation tool have been integrated with Monte Carlo method using of Palisade @Risk software. The new version of the simulation tool allows to estimate the impacts as probability distributions per each scenario. To ensure continuity with the previous research, the distributions parameters are the average values, updated according to the most recent date, considering 15% of variability. To conclude, a sensitivity analysis was conducted among the Linear Economy scenario and three different CE scenarios, based on the following four impact category indicators: (i) the Global Warming Potential (GWP) to assess the potential environmental emissions [kg $CO_{2\text{-eq.}}$], (ii) the Total Profit for the supply chain ($PRFT_{SC}$), together with (iii) the Total Cost to the users (TC_{user}) to assess the potential economic impacts [€], and (iv) the Full Time Equivalent (FTE) to assess the potential social impact on the employment opportunities. The above-mentioned CE scenarios are introduced as follows: (i) the Lifespan Extension where redesign strategies and continuous maintenance and repair activities are implemented to extend products' lifespan, (ii) the Pay-per-Wash where the service-based business model is introduced, i.e. high-quality and low-consumption WMs are assumed to be installed against payment of a user fee based on the available washing cycles, and (iii) the Advanced Refurbishment where the WMs are refurbished twice and finally recycled.

Findings

Based on these premises, results are reported in **Errore. L'origine riferimento non è stata trovata.**. First, the traditional Linear scenario was analyzed to give a representation of the present cradle-to-grave stream. The Linear scenario was compared with the three CE scenarios (Lifespan Extension, Pay-per-wash, and Advanced Regeneration). The best results of the sensitivity analysis are reported below. The Advanced Refurbishment scenario is the most emission-reducing model, with a probability equal to 57.4% of the simulated cases and an average of emissions equal to 247.10 kg $CO_{2\text{-eq}}$. per WM, compared to 305.60 kg $CO_{2\text{-eq}}$. per WM of Linear Scenario. By observing the economic impacts, all CE scenarios generate a lower TC_{user}, as well as a lower $PRFT_{SC}$. In the first case, the Pay-per-Wash scenario has the best performance. Indeed, in 55% of cases it has a lower TC_{user} than the Linear scenario, in average equal to 111.17€ per user compared to 131€ per user. While, in the last case the Lifespan Extension scenario has the smallest deviation from the Linear scenario. Indeed, only 47% of cases has a highest profit, but on average generates $PRFT_{SC}$ of 110.27€ per WM. Finally, the Pay-per-Wash scenario gives a better performance in terms of social impact in 67% of the simulated cases, with an average of 153,042 FTE, due to the introduction of new activities for the reverse flow management and the maintenance activities. Finally, the use phase is confirmed as the most critical for each impact analyzed in all the scenarios. Indeed, the users' choices can affect various aspects, from the purchase of the product on which is based the European requirement and the profits of the entire Supply Chain, the way of use during the washing phases or disposal the product which impact on cost to be incurred and the environmental impact and the resources consumption.

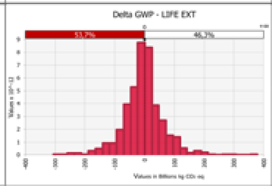
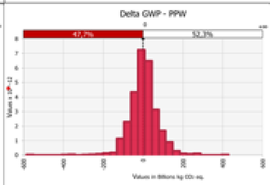
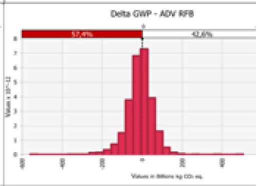
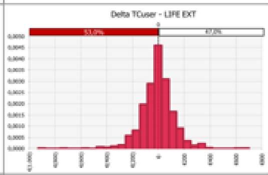
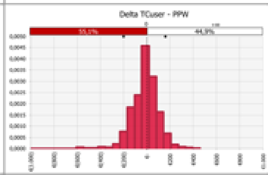
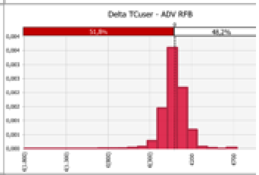
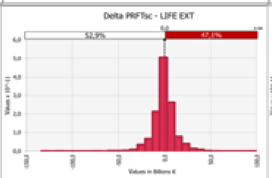
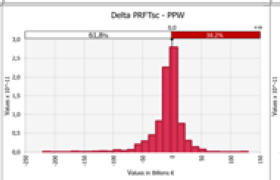
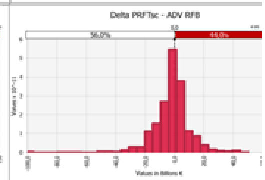
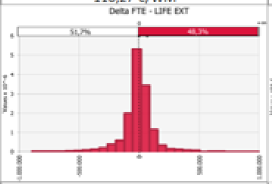
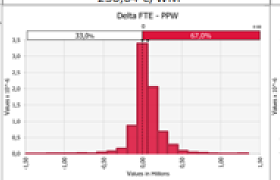
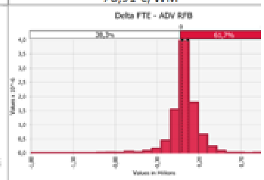
Impact	Value	Linear Scenario	Lifespan Extension	Pay-per-Wash	Advanced Refurbishment
Environmental impact	Statistical analysis	-			
	% of positive impacts for CE	-	53,70%	47,70%	57,40%
	Average	335,53 kg di CO_2 eq/WM	305,60 kg di CO_2 eq./WM	343 kg di CO_2 eq/WM	274,10 kg di CO_2 eq/WM
Economic impact for users	Statistical analysis	-			
	% of positive impacts for CE	-	53%	55,10%	51,80%
	Average	131€/persona	118€/persona	111,17€/persona	122,57€/persona
Economic impact for the Supply Chain	Statistical analysis	-			
	% of positive impacts for CE	-	47,10%	38,20%	44,00%
	Average	160,24 €/WM	110,27 €/WM	-230,64 €/WM	70,91 €/WM
Social impact	Statistical analysis	-			
	% of positive impacts for CE	-	48,30%	67,00%	61,70%
	Average	103.721 FTE	89.595 FTE	153.042 FTE	129.481 FTE

Figure 1. Matrix of results, including environmental, economic and social impacts for each scenario analysed

Discussion/Conclusion

The above results show the absence of a single win-win-win circular scenario for all the impact categories compared to the Linear economy baseline, but each one has improving aspects and potential benefits in at least two impact categories. Indeed, the Advanced Refurbishment activities significantly reduce emissions thanks to an increasing recycling of materials and products in the industrial system. The Pay-per-Wash scenario presents the lowest average cost for the user. Costs reduction is mainly due to lower service rates compared to the purchase cost and a better behavior that reduces consumption and the related expenses. Looking at social impacts too, the last scenario has a greater potential, thanks to new job opportunities introduced by a service-based business model, which need to manage reverse logistics, maintenance, and repair activities. Finally, as regards the Supply Chain, no scenario analyzed equals or exceeds the profits generated by the traditional sale of new products. Nevertheless, this research can introduce future ones, which aim to identify the combination of circular strategies that can be successful on all impact categories. The framework and the simulation tool can be further explored too, trying to introduce other impact indicators, such as for water consumption, or trying to adapt it to other product categories. In conclusion, the tool set out in the project is used for research purposes, but it can become a valuable decision support tool for companies, because of its forecasting peculiarity on possible results of a new business model and associated costs, as well as for institutions, since its large-scale application can support the introduction of new rules and polices towards the CE transition.

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Promoting the transition to the circular economy through best practices: the case of the Italian circular economy stakeholder platform (ICESP)

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Abstract

The objective of this research was to conduct a qualitative analysis of industrial sectors and life cycle phases to gather valuable information for the dissemination of best practices. This work involved revising the database, updating the numbering of good practices (GPs) based on their publication date on the platform, and incorporating new GPs published on the Italian Circular Economy Stakeholders Platform (ICESP). The sectoral qualitative analysis concentrated on seven sectors identified by the new Circular Economy Action Plan. Additionally, the research involved a review and validation of the Italian Circular Economy Stakeholder Platform database to evaluate the completeness of the information contained within the respective forms, with the aim of requesting potential additions from the proposing organizations.

Keywords: *Circular Economy; Circular Economy Stakeholder Platform, Good Practices; Green Deal; Industrial sectors.*

Introduction

Climate change, population growth and global consumption rates have fundamentally challenged the linear production and consumption model, underscoring the necessity of adopting circular production and consumption paradigms [1]. Circular Economy Stakeholder Platforms are instrumental in disseminating knowledge on circular economy issues, mapping best practices, and fostering multistakeholder dialogue [2]. These platforms play a pivotal role in facilitating the transition by serving as digital infrastructures that voluntarily and freely connect different actors, thereby enhancing knowledge sharing, comparison, and networking among the various stakeholders of the quadruple helix. This, in turn, promotes the exchange of practices and knowledge. Circular economy best practices serve as a crucial tool in advancing the transition towards more circular production and consumption models [3].

The European Circular Economy Stakeholder Platform (ECESP) was launched in March 2017 as a joint initiative between the European Economic and Social Committee (EESC) and the European Commission to support the implementation of the first Circular Economy Action Plan [4]. The ECESP platform functions as a 'Network of Networks,' transcending sectoral activities and highlighting cross-sectoral opportunities and challenges. By leveraging the European platform, it promotes the dissemination of the circular economy concept at national, regional, and local levels, facilitating access to information and establishing a framework for the exchange and discussion of best practices [5].

The Italian Circular Economy Stakeholder Platform operates through six Working Groups and three Transversal Working Groups, which are open to participation by all stakeholders, including non-members of the platform. The work conducted by these various Working Groups is discussed and presented on ICESP, with the results subsequently displayed on European Circular Economy Stakeholder Platform (ECESP) for comparison with other member states. The objectives of the platform include fostering the dissemination and diffusion of knowledge, promoting dialogue among Italian stakeholders involved in various circular economy initiatives, mapping national good practices, and promoting the integration of national initiatives. Additionally, the platform aims to simplify cross-sectoral dialogue and interactions through a permanent operational tool and to disseminate Italian excellence and the distinctive Italian methodology of implementing the circular economy [6].

Methods

The objective of the research was to conduct a qualitative analysis of industrial sectors and life-cycle phases to gather useful information for the dissemination of best practices. The life cycle phase analysis entails classifying the four areas identified by the GPs, specifically: innovation and investment, production, consumption, and waste management. The qualitative analysis involved reviewing case studies, revising the database, updating the numbering of good practices (GPs) based on their publication date on the platform, and incorporating new GPs published on Italian Circular Economy Stakeholder Platform (ICESP) into the matrix. The phase/sector matrix summarizes the distribution of GPs by both phase and sector, consisting of 4 phases and 42 sectors. These phases are further subdivided into 13 sub-phases through a second-level analysis to enhance the functionality of the qualitative analysis of GPs.

The methodology used for assessing good practices involved an analysis based on two dimensions: the product lifecycle phase and the reference industrial sector. To achieve a clear mapping of the good practices, the matrix was constructed to associate the GPs present on the Italian Circular Economy Stakeholder Platform (ICESP) with different phases and industrial sectors. The lifecycle stage analysis categorizes the four areas identified by the good practices, as depicted in Figure 1, into distinct phases: 82 GPs are assigned to the Innovation and Investment phase (Blue), 98 GPs to the Production phase (Green), 18 GPs to the Consumption phase (Red), and 114 GPs to the Waste Management phase (Yellow). It is significant to note that the Waste Management phase is the most represented. Additionally, these phases are further subdivided into thirteen detailed sub-phases through a secondary level of analysis.

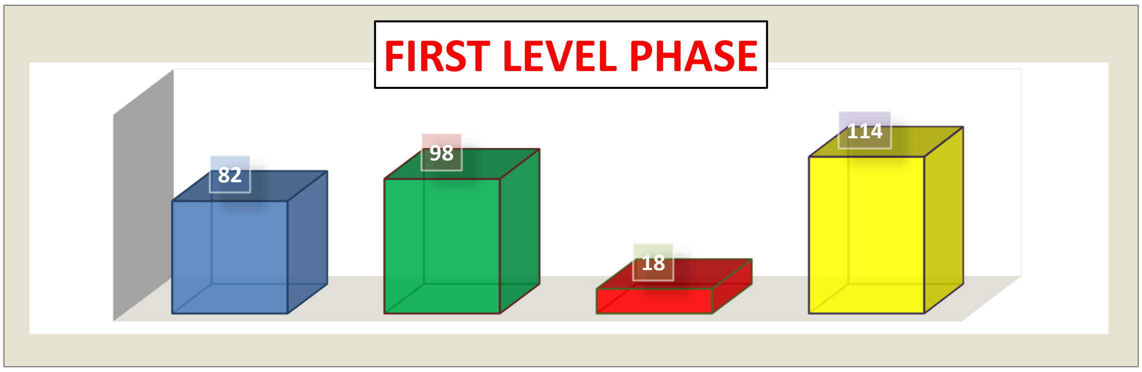

Figure 1. Good Practices distribution by phase - 1st level

The sectoral qualitative analysis encompassed the most represented sector, the recycling sector, as well as the six sectors identified by the new Circular Economy Action Plan, which warrant focused attention due to their substantial resource use and significant circularity potential. The qualitative analysis included: 1) analysis of the reference sector; 2) life cycle phases; 3) thematic scope; 4) territorial distribution; 5) types of organisations; 6) barriers, criticalities and limitations; 7) replicability of good practices.

Findings

The research indicates that one of the most recurring critical issues within the ICESP database pertains to regulatory barriers, which are often highly heterogeneous across different regional territories. To facilitate the transition to a circular economy, it is essential to promote good practices, supported by local public institutions and bodies. Additionally, the study reveals that to foster the replicability of good practices, training and knowledge dissemination are fundamental pillars. The transition from a linear to a circular economy necessitates not only extensive research and development activities on the life cycle of products and raw materials but also a profound cultural shift among companies and civil society. Education and awareness-raising initiatives have the greatest potential to inspire behavioral change towards circular and sustainable business models. Several necessary and potentially feasible measures can be identified to advance the development of the Italian circular economy and promote the identification of new good practices for publication on the Italian Circular Economy Stakeholder Platform (ICESP). The first measure to make circular economy activities replicable concerns the promotion of public awareness campaigns to foster behavioural changes that encourage a reduction in waste and favour the recycling of products. Further actions significant could be:

- identify national indicators for the proper evaluation and measurement of the transition;
- promote the Italian Circular Economy Stakeholder Platform (ICESP) platform to CONAI and the Plastic Rubber Federation to promote the implementation of new best practices in the packaging and rubber and plastics;
- promote Slow fashion and eco-design to the Italian fashion industry;
- support sustainable dismantling practices;
- encourage Italian SMEs to favour the recovery and reuse of secondary raw materials instead of using virgin raw materials.

The ICESP highlights a significant lack of good practices in the transport sector, which is directly responsible for a quarter of Europe's CO_2 emissions. Consequently, there is a clear need to promote the ICESP platform to the sector's federations and associations, initiate awareness-raising campaigns among citizens, and encourage the widespread use of public transport. Additionally, improvements have been made by requesting updates and additions from organizations with incomplete or outdated good practices.

Conclusion

This project implemented a comprehensive process of mapping, researching, and analyzing the good practices present on the Italian Circular Economy Stakeholder Platform(ICESP). The aim was to update the database, assess the conditions of various sectoral and territorial organizations, and ultimately encourage the implementation of circular practices across the national territory. Despite the seemingly small statistical representation of the database, which contains 214 good practices, the research revealed that circular practices are a valuable tool in promoting the transition towards more circular and sustainable models of consumption and production. In conclusion, good practices (GPs) represent an effective means to foster the transition towards more circular consumption and production models. Their replicability encourages the adoption of more virtuous behaviors. Notable improvements were achieved by requesting updates and additions from organizations with incomplete or outdated GPs. The analysis proved particularly useful for the most represented sector and the six sectors identified by the Circular Economy Action Plan (PAEC). The report provided guidance to the Italian Circular Economy Stakeholder Platform (ICESP) platform on upgrading to the standards set by the European Circular Economy Stakeholder Platform (ECESP). Looking to the future, public awareness campaigns should be promoted to encourage behavioral changes that reduce waste and promote product recycling. The research has offered valuable insights into how good practices can be applied universally across all production sectors.

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Evaluation of the circularity economy of the Department of Life and Environmental Sciences-UNIVPM, application of the new technical specification UNI/TS 11820:2022

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Abstract

The transition towards a circular economy model, going beyond the now never-dated linear economy, is necessary if we want to guarantee sustainable development.

About the calculation of the circularity index, until the end of 2022 there was no univocal method to calculate it. In the literature was possible find different indicators and methodologies, therefore non-uniform procedures, so the results cannot be compared with each other.

The hope for the future is that the UNI/TS 11820 technical specification, the protagonist of this work, can measure and evaluate the circularity performance of an organization, and standardize the circularity calculation methodology, making the results comparable. In this project, the circularity index of the Department of Life and Environmental Sciences (DiSVA) of the polytechnic university of March was evaluated. The evaluation was obtained by responding to the 71 indicators proposed by the technical specification, obtaining a result of 64%.

Keywords: *Circular Economy index; UNI/TS 11820:2022; Sustainable development; indicators..*

Introduction

Circular economy

Currently, most organizations exploit and use a production model that we can define as a "linear economy", which we can summarize as: take-produce-dispose.

Therefore the main characteristics of this economic system are those that are unfortunately best known; extraction of "new" raw materials, which are used as inputs in production processes, exploitation of non-renewable resources and, finally, creation of goods which, once used, reach the end of their life in landfill.

As Sariatli claims in one of his 2017 publications: "the linear economy represents an economic model that is harmful to the environment and which does not allow essential services to be provided to the growing world population".

The linear economy was very successful in generating material wealth in industrial countries until the 20th century, but it proved unsustainable, causing major problems, such as: the growing accumulation of waste and the excessive exploitation of raw materials.

Previously, the absorption capacity of planet earth, and the excessive belief in having inexhaustible raw materials, meant that we did not focus on the problems.

As time passed, the shortcomings of the linear economic system became apparent, and some authors belonging to different disciplines began to propose ideas with the aim of arriving at a sustainable solution (Sariatli F., 2017).

It is therefore essential to lay the foundations for a paradigm shift that gives rise to a new industrial policy, a new way of thinking, aimed at sustainable development.

To make the transition towards a circular economy, a radical structural and cultural change is necessary: carefully reviewing consumption models and innovation are the basis of change. It is therefore necessary to abandon the linear economy, overcome the recycling economy, in which only a part of the waste is reused and the raw materials continue to be exploited, to finally arrive at the circular economy.

We can define the circular economy as a system in which materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes such as maintenance, reuse, refurbishment, remanufacturing, recycling and composting. The circular economy addresses climate change and other global challenges, such as biodiversity loss, waste and pollution, by decoupling economic activity from the consumption of limited resources.

The measurement of circularity

The adoption of circular economy principles over the years is becoming increasingly important and at the center of every debate to achieve sustainable development objectives. In the past, it was necessary to establish and use measurement tools related to the circular economy to support professionals who were responsible for monitoring the effects following the adoption of the principles inherent to the circular economy.

To this end, circular economy indicators have been developed in recent years, with the aim of monitoring and developing its progress.

The measurement of circularity has represented and still represents an important requirement for achieving results, objectives, and above all for making the transition from a linear economy towards a circular economy measurable.

In 2015 the Ellen-MacArthur foundation stated that a complete and exhaustive methodology leading to the quantification of the circular economy had not yet been defined.

Several studies have shown that the lack of measurement methods such as indicators has been recognized as a limit to the transition from linear to circular (Angelina De Pascale, 2021).

Methods

The Technical Specification UNI/TS 11820:2022

Given the high availability of indicators, the difficulty in comparing the level of circularity of different subjects is evident. In response to this, the UNI/TS 11820:2022 technical specification has been published by UNI (Italian National Unification Body), which is part of a broader context that will lead to the development of the European ISO 59020 (International Organization for Standardization) standard that will provide a tool for measuring circularity at the international level, thus having the possibility of comparing values.

The UNI/TS 11820:2022 technical specification "Measurement of Circularity - Methods and Indicators for the Measurement of Circular Processes of Organizations," published on November 30, 2022 by the Italian standardization body UNI, aims to:- Propose a broad set of indicators; - Include all aspects of the life cycle; - Have a quantification system in place, define a framework and specific procedures. The TS is under revision and is expected, that the revised version will be published by 2024.

Purpose of UNI TS 11820:2022 is to measure and evaluate the circularity performance of an organization and defines a set of indicators applied at the meso and micro level, suitable for evaluating, through a rating system, the level of circularity of an organization or group of organizations.

The measurement system does not stipulate a minimum threshold value of circularity but allows for the assessment of the level achieved by the organization, compared to the maximum attainable level. The technical specification therefore aims to improve the level of circularity over time.

The technical specification defines a set of circular economy indicators suitable for assessing, through a measurement system on a 100 basis, the level of circularity of an organization or group of organizations.

The technical specification is applicable at the following levels:- Micro (individual organization, local government); - Meso (group of organizations).

In terms of analysis the first thing to do is to define the boundaries of the system, after which based on what each indicator requires we proceed with data acquisition.

To be precise, the indicators referred to in this technical specification are 71.

Once all the data have been collected, and then all the completable indicators have been compiled, one proceeds with the calculation.

Description of the case study, the Department of Life and Environmental Sciences

This study aims to quantify the level of circularity of an organization. Specifically, reference is made to the Department of Life and Environmental Sciences and Sciences

(DiSVA) of the Polytechnic University of Marche, located at the city of Ancona, via Brecce Bianche 60131.

Description of information needed for the purpose of applying the technical specification to DiSV

Initially, the evaluation boundary being measured (system boundaries) was defined in order to understand its requirements and key characteristics at the project planning stage, and in essence establish the type and amount of data useful for analysis (Fig. 1).

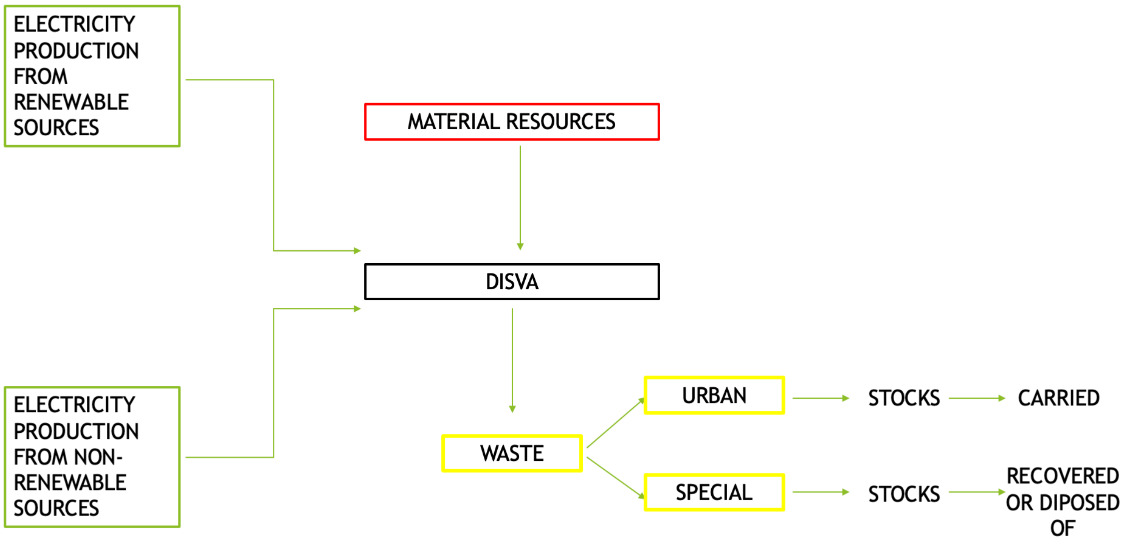

Figure1. System boundaries

We proceeded by selecting the indicators of interest were selected, thus not considering indicators referring to a product as they were not applicable to the case at hand.

Before starting with the collection of data necessary for the development of the above analysis, the year to be referred to was set. Considering that at the time of beginning thesis work it was necessary to have access to data for an entire calendar year, it was decided to refer to 2022. Once the process was planned, it began with the collection of data.

Calculation of the total value of the circularity index

The UNI/TS 11820:2022 technical specification distinguishes indicators into the following classes:

- material resources and components
- energy and water resources
- waste and emissions
- logistics

- product/service
- human resources, assets, policy and sustainability

The department's total circularity index was calculated.

The table below (Tab. 1) summarizes the calculation for obtaining the total percentage circularity indicator.

Table 10. Summary representation total circularity index calculation

TOTAL CIRCULARITY INDEX	INDEX VALUE	INDEX NUMBER
TOT CORE INDEX	5	7
TOT SPECIFIC INDEX	17,25	32
TOT REWARDIG INDEX	5	5
GENERAL TOTAL	27	45
IC	0,64	
IC%	64,00	

In carrying out the entirety of the analysis, 44 indicators were considered, as 15 were found to be unsuitable for a reality such as that of a university department and 12 were not taken into account as they refer to the type of evaluation related to the product. This is reported in "Allegato A" (attached as a document to the paper in question).

At the end of the analysis, the value of the department's total circularity index turns out to be 64 percent. The results are represented by means of a typical so-called "radar" graph (Fig. 2), which provides a clear and immediate view of the situation. At the apexes of the hexagonal-shaped web are shown the six different categories of indicators.

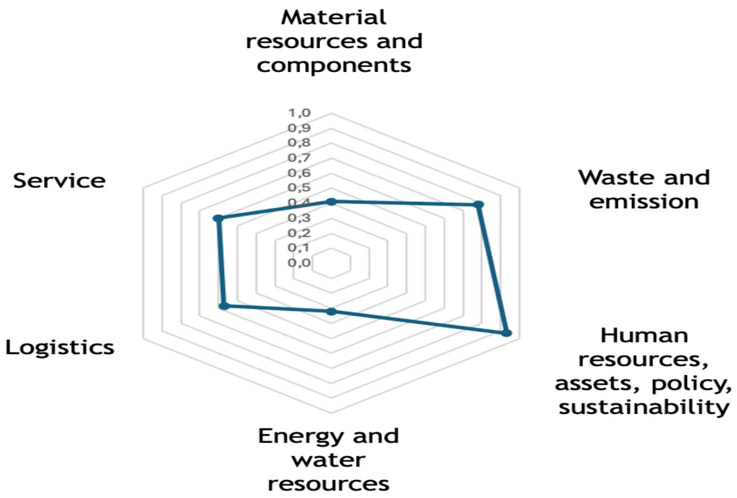

Figure 2. Circularity index representation for each class of indicators

The results show us that the percentage related to the circularity index for the different classes was sufficient and/or more than sufficient, in detail:

- indicators related to waste and emissions = 78%
- Indicators related to human resources, assets, policy, and sustainability = 93%
- Indicators related to logistics = 57%
- Indicators related to product/service = 60%

The positive influence of indicators related to human resources, assets, policies and sustainability should be emphasized in particular these categories (Human resources, assets, policy and sustainability) has proven to be a cornerstone of the Department, which makes it one of its strengths to discuss, expound, and export the concept of circular economy outside the university context as well.

Indicators related to waste and emissions also proved to be a real strong point in this analysis due to the care and meticulousness with which DiSVA, in collaboration with the municipality of Ancona, in this case "Ancona Ambiente", addresses the issue concerning the collection and disposal of urban and special waste.

Finally, regarding the aspect related to emissions, the assessment of its carbon footprint (indicator 19) plays an important role, a tool that allows to assess the environmental impacts that activities have on climate change. In fact, the figure makes it possible to estimate the atmospheric emissions of greenhouse gases caused by a product, service or organization, generally expressed in tons of CO_2 equivalent (i.e., taking as a reference for all greenhouse gases the effect associated with the main one of them, carbon dioxide or carbon dioxide) over the entire life cycle of the system under analysis (ISO, 2017).

On the contrary, two classes of indicators, the Material Resource and Component Related Indicators and the Energy and Water Resource Related Indicators, respectively, have the two lowest percentages, 40% and 20%, respectively.

As for the category of material resources, we can find the critical points in the following indicators:

- Indicator 2: Raw materials and secondary material resources purchased and/or acquired from local suppliers compared to total raw materials purchased and/or acquired. The value obtained from the calculation of this indicator (0.15) turns out to be relatively low because from what turned out in the sample of purchase bills examined most of the raw materials and secondary material resources are not sourced locally, which is why the value of this indicator is significantly lowered.
- Indicator 3: Material resources (inputs) with a tracking system (e.g., product passport) compared to total material resources (inputs).The value obtained from the calculation of this indicator is 0 because from the information extrapolated there are no material resources equipped with any tracking system, as it is not required by the current regulations.
- Indicator 5: Renewable raw materials (input) compared to total material resources (input).This indicator shows a "critical" value because in the university context most of the incoming material resources deal with laboratory material, thus non-renewable. The exception is stationery material (considered as such, due to the purchase of paper, and recycled plastic). However, this material accounts for 10 percent of the total material input and does not particularly contribute to the indicator value.
- Indicator 6: Secondary material resources and/or by-products and/or components subject to upcycling compared to total secondary material resources and/or by-products and/or components. This indicator was rated 0 because there were no secondary material resources and/or by-products and/or components subject to upcycling, considering the latter term as the process by which secondary material resources and/or by-products are transformed or converted into new materials, components or products of better quality, better functionality and/or higher value. Since this is primarily laboratory consumable material at the end of its use it must necessarily be disposed of.

With regard to the class of Indicators related to energy and water resources, the indicators for which a lower value was obtained are number 13 and number 14, in addition to the attribution of value 0 to indicator number 15. These indicators refer to electricity and thermal energy purchased from renewable sources, respectively. For these indicators to positively influence the total circularity index in the future, it will be necessary for the supplier's energy mix to be more unbalanced toward more renewable energy.

Indicator 15, on the other hand, deals with the quantification of water from recovery or recycling compared to the total amount of water used. No water from recovery or recycling was used in the year 2022, a factor that should be taken into account in order to raise the university's circularity value.

Conclusion

The present work allowed the estimation of DiSVA's level of circularity through the application of the recently published UNI/TS 11820 technical specification.

The results obtained are extremely promising as the Department showed a more than sufficient overall circularity index of 64% showing some strengths, especially in the already mentioned categories of:

- waste and emissions;
- human resources, assets, policy, and sustainability;
- Logistics;
- Product/service.

On the other hand, the technical specification has allowed us to highlight some weaknesses that could be invested in, in the years to come, with a view to sustainability.

Among these, indicators related to material resources and components suggest the need to incentivize (whenever possible) purchasing from local producers/distributors, preferably with green certifications (i.e., procedures and purchasing processes, used by private or public organizations, to purchase goods and services with less environmental impact), as highlighted by the category related to the product and service.

The low score (32 percent) in the category of energy and water resources, identifies the critical issue of not using water from reclaimed and/or recycled sources.

In order to improve the score in this category, it would also be desirable to choose energy distributors with a different energy mix, in which the contribution of renewables has a greater weight.

Since this is a university department, whose consumption is closely related to research, it is noteworthy that there are aspects on which it is almost impossible to intervene, such as assuming increased upcycling activities.

This is also because of safety issues that necessarily require the disposal of almost all waste leaving the laboratory, which is often classified as hazardous.

In addition, some considerations must be made regarding the application of the technical specification to a situation such as that of a research department.

In fact, it should be remembered that the technical specification is of recent publication and there is therefore still little experience and little possibility of comparison with other case studies. It was possible to compile 75 percent of the specific indicators available, more than meeting the minimum limit of 50 percent set by the technical specification with respect to the total. However, from the total it was decided to exclude 5 (of the 71, or rather 59 considering only those for services) indicators because they were considered not applicable to the specific case study. Reference is made, in particular, to those related to industrial symbiosis (numbers: 51, 52,53, 54, 55), a strategy that is difficult to think of in a university context, where there is no waste that can potentially be valorized by other realities. Practical difficulties were then encountered when retrieving data, often available for the entire university complex and not just the departmental perimeter.

For aspects such as, for example, material resources there is, to date, information available regarding provenance and quantities but reduced or absent is data regarding weights and packaging (information that is probably easier to locate in the case a company with a well-detailed and above all more reproducible production cycle).

The result obtained by DiSVA can be considered satisfactory and represents a starting point for the improvement of circularity and thus a decrease in terms of impact on the environment in the future, giving strength to the result obtained by the UI Green Metrics Rankings that sees UNIVPM ranked 7th in Italy and 107th in the world.

The evaluation of the Department's circularity could be taken into consideration as a good practice through periodic (e.g., biannual) monitoring of indicator trends.

This thesis confirms the importance of the new technical specification in supporting the creation of circular strategies even in realities such as the university. The integration of sustainability aspects into the everyday life of each individual citizen, community, and especially each political movement is the only way to succeed in distancing ourselves from the much-discussed tipping point as soon as possible and to be able to return to respecting the boundaries of our planet earth.

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A study of the aging of bituminous mixtures recycled in a specialized plant and their applicability on roads

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Abstract

Reclaimed Asphalt Pavement (RAP) is the recycled bituminous mixture currently integrated into new bituminous mixes at percentages of up to 30%. Natural aging process of bitumen is accelerated by high temperatures during hot recycling. To evaluate this, the experimental program involves studying the rheological behavior of bitumen in five mixes containing 40% RAP and heated to various temperatures in a specially designed plant. Subsequently, the mechanical behavior of five mixes composed of 40% RAP and different rejuvenating additives in varying percentages is analyzed. It was observed that the binder's deterioration is contained if the heating temperature in the specially designed plant is below 200°C, and that the presence of RAP increases the stiffness of the bituminous mixtures. The obtained results were compared with the usage limits specified by the Tender Specifications (CSA) to verify the mixtures' adequacy.

Keywords: *Circular economy; RAP; Recycling plant; Aging; Rejuvenating additives.*

Introduction

Bituminous mixture is composed, on average, by 95% of aggregates from different origins and sizes, and 5% of a bituminous binder (artificial bitumen) [1]. From a circular economy perspective, bituminous mixture derived from the milling of road pavements have been recovered and recycled for some time. This type of material is called Reclaimed Asphalt Pavement (RAP) according to UNI EN 13108-8 (2016). It is integrated at a defined percentage into a new bituminous mixture, meaning virgin bitumen and aggregates. Typically, bituminous mixtures containing up to 30% RAP are used in the higher layers of road pavement [2] and this limit is due to the presence of aged bitumen adhering to the surfaces of virgin aggregates. Aging involves the change in the physical-chemical properties of bitumen, causing a loss of its performance characteristics [3]. This process could be accelerated by the hot recycling activity of RAP when the material is not properly treated [4]. Therefore, during the heating of RAP, necessary to remove moisture adhering to the aggregates' surfaces, direct contact of the aggregates with the burner flame must be avoided [5]. The engineering application of RAP can be improved with rejuvenating additives that restore the chemical structure of aged bitumen [6]. This project initially studied the rheological properties of the recycled binder to determine any additional deterioration of bitumen during the production of 40% RAP mixtures and its suitability as a bituminous binder for new road pavements. In the second phase, it was evaluated which rejuvenating additive is most effective mechanically in reducing the aging of bitumen in 40% RAP.

Methods

In the first phase of the experimental program, the rheology of the recycled binder, contained in five bituminous recovery mixtures, was studied to determine any additional deterioration of bitumen during the production of the mixtures. The mixtures differ in the temperature at which the RAP was heated in a specially designed dryer. This dryer allows preheating up to 50% of RAP in the gap between its inner and outer walls (recycling ring) so that the recycled material does not come into direct contact with the burner flame. No virgin bitumen was added to any mixture to avoid altering the recovered binder's properties. Five samples were prepared for this phase, one for each mixture, as described in Table 1.

Table 11. Samples analyzed in the first phase

% of RAP	Heating temperature in plant (°C)	Name of sample
100%	Not heated (≈ 20°C)	RAP-TA
40%	150	RAP150
40%	170	RAP170
40%	190	RAP190
40%	210	RAP210

The recycled bitumen was extracted from the RAP mixtures using the Soxhlet extractor (BS EN 12697-1, 2020) with the aid of the solvent tetrachloroethylene, and subsequently separated from the bitumen with the Rotavapor (BS EN 12697-3, 2018). The physical and rheological characteristics of the bitumen obtained from each mixture were then evaluated through the penetration test (BS EN 1426, 2015) and the ring&ball test (BS EN 1427, 2015), aimed at assessing the bitumen's softening point [7]. The Frequency Sweep Test (BS EN 14770, 2012) was then conducted to determine the complex shear modulus G^* and the phase angle δ of the sample using the Dynamic Shear Rheometer (DSR) in oscillatory mode. With the same instrument, the samples were subjected to the viscosity test with the cone-plate method (BS EN 13702, 2018) at 135°C.

The second phase of the experimental program involved the mechanical characterization of four bituminous mixtures to be used in the wear layer of road pavement, produced in the same specially designed plant (Table 2).

Table 12. Samples analyzed in the second phase

% of RAP	% and type of additive	Total bitumen (recovered + virgin)	Name of sample
40%	4% add. E	5,96%	E1
40%	4% add. V	5,30%	V2
40%	4% add. E	5,30%	E3
40%	5% add. E	5,30%	E4

For the mechanical characterization of the mixtures, six cylindrical samples with a diameter of 100 mm were prepared for each mixture using the Gyratory Compactor (EN 12697-31). The Indirect Tensile Stiffness Modulus test (ITSM, BS EN 12697-26, 2018) was conducted at three different temperatures, simulating the conditions the road pavement typically experiences over a year. Subsequently, the Indirect Tensile Strength test (ITS, BS EN 12697-23, 2017) was conducted on specimens stored in a water bath at 40°C for 48 hours and on unconditioned specimens. The Indirect Tensile Strength Ratio (EN 12697-12, 2018) and the Indirect Traction Coefficient (CTI), a parameter related to the vertical deformation of the specimen, were calculated [8].

Findings

From the penetration test, it was observed that as the heating temperature of the samples in the plant increased, the penetration decreased due to the increased stiffness of the binder. It decreased from 8.80 dmm for RAP150 to 7.65 dmm for RAP210. The penetration in the sample heated to 190°C is higher probably due to the environmental conditions under which the test was conducted (higher atmospheric temperature). Additionally, an increase in the softening point was recorded as the heating temperature in the plant increased, confirming the stiffening of the samples (from 82.9°C for RAP150 to 97.4°C for RAP210). This result is also shown by the trends of G* and δ obtained from the Frequency Sweep Test with varying oscillation frequencies of the rheometer plate. Specifically, the largest increase in G* and δ at high temperatures was recorded for the RAP210. The viscosity test results with the cone-plate method showed that the viscosity of RAP210 was significantly high (≈ 2.98E+04 mPa*s) and the viscosity of RAP170 was higher (≈ 3.16E+04 mPa*s) probably due to residual filler present in the binder. The rejuvenating effect of the additives is observed in the reduction of ITSM and ITS. The ITSM of the sample decreased with the increase in temperature, and its values were higher than those of traditional mixtures containing low percentages of RAP, which are usually about 4000 MPa at 20°C. All ITS values exceed the reference parameters for the wear layer set by the Tender Specifications of ANAS (CSA), ranging from 0.72 to 1.60 MPa for the virgin bitumen. On the other hand, the CTI of the mixtures complied with CSA limits (≥ 65 MPa). From an engineering application perspective, a higher CTI is advantageous. The data from the second experimental phase also showed that the higher percentage of bitumen present in E1 significantly influenced the mechanical characteristics of the mixtures: it reduced ITSM and ITS, making the mixture less resistant than others, decreased the CTI, making it less suitable for application compared to others, and increased the ITSR, giving it greater water resistance.

Discussion/Conclusion

Important conclusions can be drawn from each experimental phases. The rheological study of the samples revealed that heating the RAP-containing mixtures in the plant accelerates the aging process of the binder, as demonstrated by the reduction in penetration and the increase in the softening point. However, based on the trends of the rheological parameters, it has been possible to state that the binder deterioration is limited if the heating temperature is below 200°C thanks to the specific RAP recycling method. This confirms the possibility of using a 40% RAP mixture for road pavements only if preheated at lower temperatures. The mechanical behavior study of the samples showed that the presence of RAP increases the stiffness of the bituminous mixture and that the bitumen percentage is the parameter that most influences the mechanical characteristics. Since the ITSM, ITS, CTI values for the differently composed mixtures did not have significant differences, it can be stated that additive E is as effective as additive V in terms of the rejuvenating effect of the mixtures. This means that the softening effect of the additive does not significantly depend on either the percentage or the type of additive analyzed. Finally, the ITS values did not fall within the CSA limits because a percentage of RAP higher than the currently allowed 30% was used.

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Application of the Pay-As-You-Throw waste management system in the municipality of Martina Franca

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Abstract

The study reviews the current landscape of Pay-As-You-Throw (PAYT) systems for MSW (Municipal Solid Waste) management and assesses the feasibility of implementing this approach in Martina Franca, among the first municipalities in Southern Italy to consider such a service. A three-month experimental campaign measured MSW disposal from local households, providing data for estimating annual household waste production more accurately. An algorithm was developed to assign costs based on each user's actual MSW generation, factoring in exposures of non-recyclable waste fractions. The study demonstrated immediate economic benefits for households and laid the groundwork for enhancing recycling efficiency significantly.

Keywords: *Algorithm; Costs; Recycling PAYT; MSW.*

Introduction

Pay-As-You-Throw (PAYT) constitutes an innovative waste management strategy that has seen growing adoption in Italy in recent years [1][2]. This system calculates waste disposal costs based on the actual waste production of each household or user, aiming to drastically reduce the overall amount of municipal solid waste generated by promoting more responsible consumption behaviours and waste reduction. Additionally, it seeks to promote recycling by encouraging citizens to accurately separate their waste at source as well as actively participate in recycling programs. Positive indications [3] have shown that the implementation of PAYT has indeed led to a significant increase in recycling rates.

According to data from ISPRA [4] for the year 2022, the PAYT management model was already in effect in 1.298 municipalities, accounting for about 16% of Italian municipalities, and covering a population of 8.833.708 inhabitants, which is approximately 15% of the national population. The distribution of municipalities implementing PAYT is uneven across the country, with high concentrations in northern Italy, sparse presence in central Italy, and, in the worst cases, almost complete absence in southern Italy.

The main objectives of this study were to demonstrate the inequity of the current "Tari system" (a system established in accordance with the law n.147 of 2013 and currently predominant on the national territory) in the Municipality of Martina Franca (and by extension, the Tari system in general), as well as to demonstrate the feasibility of implementing the PAYT system. Tari is generally calculated based on the size of the property in square meters, even though the data on square meters has a minor impact on waste production [5] and the type of use (residential or non-residential). For residential properties, the number of occupants can also influence the amount. The primary goal of Tari is to cover the costs associated with the collection, transport, treatment, and disposal of municipal solid waste, as well as the costs of street cleaning. The presumptive method associated with the Tari, since its conception with the Presidential Decree 158/1999, has been proposed as a palliative, to estimate the production of waste, given the difficulty of the municipalities to carry out a precise survey of the waste produced by each citizen, and yet it is still the most used method today [5]. Furthermore, observing the analysis conducted in 2020 by CRIF ratings [6], the Tari, which is based on elements that go beyond the actual use of the service and which tends to overlook the customer's ability to contribute, represents on average approximately 30% of tax revenues for the municipalities of the Peninsula and exhibits the greatest risk of non-compliance. The predominant factor for the success of PAYT systems is the responsibilities of the population, which cannot happen in the absence of a massive communication plan, which overcomes the resistance to carefully carry out the conferment; in fact, transparency is among the predominant factors to guarantee the support of the population for PAYT systems [7]. A possible disadvantage of PAYT systems is that the complexity of the system increases with their implementation [8], however, in the face of a certainly greater management effort, it is possible to obtain overall significant benefits, both economic and environmental.

Methods

The implementation of the Tarip generally involves a roadmap that includes: 1) Sample identification; 2) Weighing; 3) Analysis of results; 4) Definition of the algorithm; 5) Verification of results and comparison with the current tariff.

A preliminary step to the implementation of such pricing was an experiment involving a sample of 1.927 households, divided into categories ranging from 1 to 6 members. Each household participating in the experiment was assigned bins with stickers from the experimental project, to indicate to the operators which households to monitor. Their task was to weigh the bins and the shared condominium bins associated with the different fractions collected, in order to provide the necessary data to derive the essential data for the Tarip algorithm. The weighing took place during the year 2023, from June 7 to July 15, and from September 18 to October 16. The measurements were recorded in an Excel file that associates each participating household's name, address, and category, as well as the quantity in kilograms of the fraction collected on collection days during the campaign period. The collected data were processed, and an estimate was made of the waste production by households over the course of a year, with the aim of attributing the costs related to the management of municipal solid waste. It was found that households are responsible for about 54% of the waste produced in the area ('QDU' will stand for waste quota produced by households, while 'QNDU' will indicate all the other categories). The current presumptive method instead estimated 80%, resulting in a disproportionate burden on citizens to the advantage of commercial users (see figure 1).

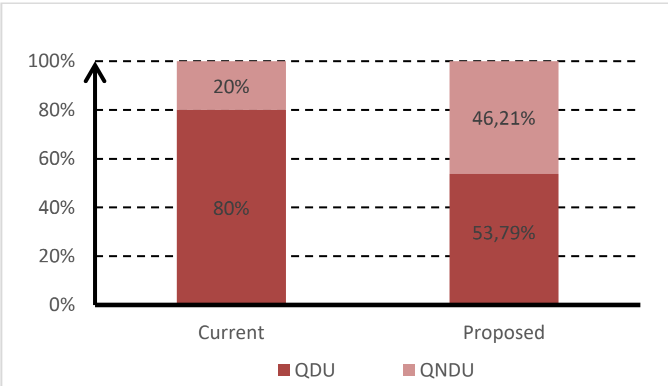

Figure 1. QDU and QNDU estimated through normalized method and through Tarip experimentation

The algorithm

The algorithm is tasked with allocating fixed and variable costs associated with the management of urban waste, financially covered respectively by a fixed tariff (Tf) and a variable tariff (Tv). However, 30% of the variable component is covered through a punctual variable tariff (Tvp, a tariff component that rewards diligent users).

Critical to the algorithm's operation in attributing the tariff to each user is the value 'kp', which is the apparent density of the unsorted residual waste (i.e., non-recyclable MSW) disposed of. This value was derived by dividing the total volume disposed of by users during the period by their respective net weight. The unit cost associated with disposing of this fraction was determined by dividing the amount of the punctual variable tariff by the annual tons of residue. This enabled the identification of the cost associated with each user's exposure of their container, as summarized in Table 1.

Table 1. Calculation of minimum prices associated with the exposure of the three different possible containers provided to users in the area.

Volume of container (litres)	36	120	360
Kp unsorted residual waste (kg/litre)	0.065		
Weight of unsorted residual waste (kg)	2,330	7,755	23,270

Minimum price (euro)	0.71	2,35	7,06
Increased price (euro)	1.00	3.00	10.0

The tariff, therefore, is composed as follows:

- Tariff = $T_f + T_{v,NP} + T_{v,P}$

where:

- Tf = fixed tariff
- Tv,NP = non punctual variable tariff
- Tv,P = punctual variable tariff
- T_{fNDU} = Kc × sup × Q_{fNDU} [m^2] [€/m^2]
- T_{vNDUnp} = Kd × sup × Q_{vNDU} [kg/ m^2] [m^2] [€/kg]
- T_{vNDUp} = Ei × frequency × 52,14 x increased price [disposals/week] [weeks/year] [€/disposal]
- T_{fDU} = Ka × sup × Q_{fDU} [m^2] [€/m^2]
- T_{vDUnp} = Kb × Q_{vDU} [€]
- T_{vDUp} = Ei × frequency × 52,14 × increased price [disposals/week] [weeks/year] [€/disposal]
- Ka, Kb, Kc, Kd = normalization parameters
- T_{fNDU} = fixed tariff for non-domestic users
- T_{vNDUnp} = non punctual variable tariff for non-domestic users
- T_{vNDUp} = punctual variable tariff for non-domestic users
- T_{fDU} = fixed tariff for domestic users
- T_{vDUnp} = non punctual variable tariff for domestic users
- T_{vDUp} = punctual variable tariff for domestic users
- Qf, Qv = fixed and variable quotas

The guidelines for the effective implementation of the process necessary to implement a pay-as-you-throw system are contained in the Ministerial Decree of 20 April 2017.

Findings

In Figure 2, the comparison between the current tariff and the Tarip calculated by the algorithm is shown for a unit without outbuildings with a single user, varying the residue exposure index. The breakdown of how the tariff develops based on varying user behaviour is reported in Table 2.

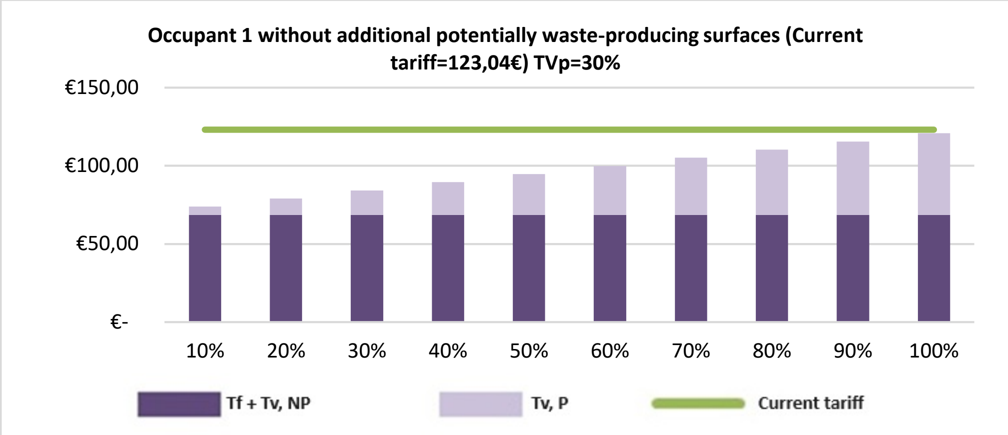

Figure 2. Proposed tariff and current tariff: Occupant 1

Table 2. Proposed Tarip amount varying with Ei compared to current Tari for Occupant 1 category.

Ei (%)	10	20	30	40	50	60	70	80	90	100
Tf+Tv,NP (euro)	68.66									
Tvp (euro)	5.21	10.43	15.64	20.86	26.07	31.28	36.50	41.71	46.93	52.14
Current tariff	123.04 €									

On the diametrically opposite end are non-domestic users, particularly sensitive cases are those associated with facilities inclined towards waste production, thus having particularly high Kd coefficients. Consider the example shown in Figure 3 and detailed in Table 3 concerning users such as dining halls and similar establishments.

Therefore, even under the assumption of the worst possible behaviour, domestic users bear a burden that is still lower than the current one. Conversely, non-domestic users, who have been significantly and unfairly advantaged so far, face the opposite situation.

Discussion/Conclusion

The implementation of the PAYT waste management system in the municipality of Martina Franca has demonstrated significant economic and environmental benefits. Through detailed data collection and analysis, it has been shown that this system not only incentivizes residents to engage in more sustainable waste disposal practices but also leads to more equitable financial contributions based on actual waste production.

The transition from the traditional Tari system to the Tarip model in Martina Franca revealed that the previous system inadequately estimated waste production, which resulted in a less efficient allocation of waste management costs. The data indicated that the actual distribution of waste production was approximately 60% from domestic users and 40% from non-domestic users, contrasting sharply with the previous assumption of 80% and 20%, respectively. This mismatch highlights the importance of accurate data in designing and implementing waste management policies that reflect the true environmental impact of different user categories.

The PAYT system also fosters greater community involvement and awareness. By directly linking waste production to cost, residents become more conscious of their waste generation and are motivated to reduce it, thereby contributing to environmental sustainability. This increased responsibility among citizens is crucial for the long-term success of any waste management program and aligns with broader goals of sustainable development.

In conclusion, the case of Martina Franca provides a compelling argument for the widespread adoption of PAYT systems across municipalities. The success observed in this municipality underscores the potential for PAYT systems to enhance waste management efficiency, promote environmental responsibility, and achieve financial equity. As more municipalities consider adopting such systems, the findings from Martina Franca could serve as a valuable model, guiding them toward achieving similar outcomes.

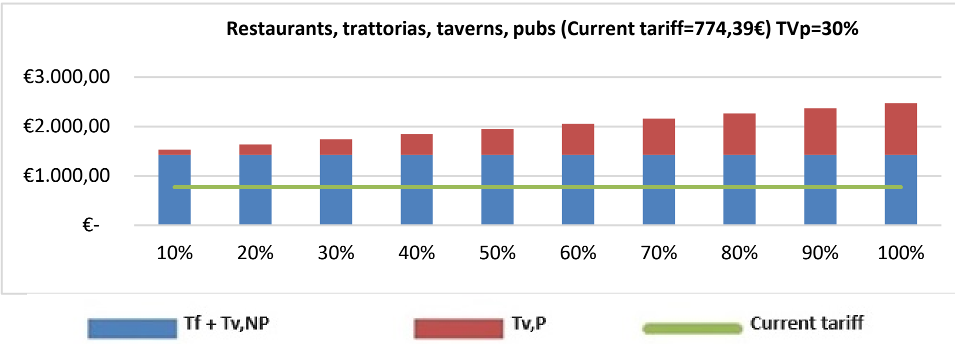

Figure 3. Proposed tariff and current tariff: Restaurants, trattorias, taverns, pubs

Table 3. Amount of proposed Tarip varying with Ei compared to current Tari for the category Restaurants, trattorias, taverns, pubs.

Ei (%)	10	20	30	40	50	60	70	80	90	100
Tf+Tv,NP (euro)	1.429.93									
Tv,p (euro)	104.28	208.56	312.84	417.12	521.40	625.68	729.96	834.24	938.52	1.042.80
Current tariff	774.39									

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Analysis of the efficiency of Italian cities using circular economy indicators: an application of Data Envelopment Analysis

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Abstract

This paper aims to analyse the efficiency of Italian cities in the management of local public services using the Data Envelopment Analysis (DEA). Fifty-nine provincial and regional capitals in Italy were examined, focusing on urban waste management, public transport and integrated water services management for 2019. Efficiency was assessed with a circular economy target output, specifically the percentage of separate collection, public transport capacity and water quality, while inputs were the city's costs. The first stage of the analysis showed that 59% of the cities achieved maximum efficiency, with twenty-three cities belonging to Northern Italy. The second stage refers to the Super-efficiency DEA, which produces a ranking of cities with different efficiency levels, showing reasonable geographical representativeness.

Keywords: *Efficiency; Data Envelopment Analysis; Circular Economy; Local Public Services.*

Introduction

Concern about climate change and the consequences of human behaviour has led public institutions around the world to take various medium and long-term measures in different areas. Growth and economic development are increasingly linked to sustainability, leading to the adoption of the concept of sustainable development. The recent Green Deal plans, initially proposed in the US and EU, reflect this change by identifying direct and targeted actions to address climate issues [1, 2]. Cities play a key role in achieving sustainable development because (1) they are crucial for the implementation of sustainable reforms [3] and (2) they independently manage different local public services in accordance with the Legislative Decree No. 267/2000. The efficient management of these services is essential for national sustainable development, as local services use inputs, generate emissions, and cause negative externalities. The economic growth model of the last 150 years, known as the linear economy, is now challenged by the new paradigm of the circular economy, which promotes the reuse of waste as raw materials [4]. The reform of the traditional production system according to the principles of the circular economy requires significant changes in cultural and productive processes, including in the management of public services.

Framework

Sustainable Development

Defending the environment has become increasingly essential due to the tangible consequences of human pollution. Key issues include atmospheric gas emissions from industry and traffic causing the greenhouse effect, uncontrolled waste and water use, which threaten future water shortages, and the growing waste production coupled with inadequate recovery or disposal policies. Sustainability, derived from the Latin "sustinere", implies supporting and preserving [5]. Despite its ecological origins, sustainability is interdisciplinary, encompassing economic, social, and cultural aspects [6]. In environmental terms, sustainability means a system's ability to continue producing desirable properties indefinitely [7] The Brundtland Report defined the concept "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [8]. The United Nations addressed environmental issues in relation to economic development as early as the 1972 Stockholm Declaration, emphasising that development must integrate environmental considerations [9]. The 1992 Earth Summit further defined sustainable development as improving quality of life without exceeding ecosystems' carrying capacity, linking economic and social development with environmental protection [10]. The core principles of sustainable development include ecological, economic, and ethical-social sustainability, often supplemented by institutional sustainability [11]. Ecological sustainability protects biodiversity, manages natural resource scarcity, and prevents species extinction. Economic sustainability involves recognising and mitigating economic growth's environmental impact by reducing non-renewable resources. Ethical-social sustainability addresses social equity, ensuring equal distribution of well-being and access to services [12]. The concept of sustainable development is included in several current policy documents, such as the 2030 Agenda of the United Nations with its 17 SDGs, the EU Environmental Action Programme to 2030, which aligns with the European Green Deal, the Green New Deal in the US, and at the Italian level, the National Strategy for Sustainable Development [13,14,15]. From these moves, the package on the circular economy, outlined in EU directives n. 849 - 852 of 2018 aims to imitate natural processes, reusing everything and not losing anything [16]. This model focuses on creating a regenerative and regenerative industrial system, using renewable energy and eliminating toxic chemicals [17]. The shift from a waste-based model to a resource-based paradigm highlights waste as a source of income, not just as a cost [18]. The principles of the circular economy apply to various sectors, including water service management, where energy and material recovery are examples[i]. Mobility also plays a key role in urban strategies, with the sharing economy facilitating a more efficient use of resources [20].

Local Public Services and Circular Economy

Italy includes 112 cities (14 of which are metropolitan cities) and the current article analyses the performance of fifty-nine, which have been selected based on data availability (Cities with available data were selected. Concerning these provincial and regional capitals, the management of three local public services in terms of circular economy indicators has bess investigated. It follows the definition of the mixed theory, which overcomes the antithesis between subjective and objective theory and links the ownership of public service performance and the satisfaction of users' needs [21]. The first field of observation for local public services starts with public transport, defined by the authoritative doctrine "paradigm of local public service, as this activity is intended to meet needs of a collective nature…" [22]. This is linked to the circular economy because it is part of the sharing economy, allowing consumers to share goods and services and rationalise their resources[ii]. In fact, using Public Transport helps reduce the three types of unsustainability caused by vehicular traffic [24]. The second service analysed is the management of municipal waste, which plays a key role in the transition to the circular economy: it provides, together with recycling, the reduction and reuse of waste, extending the life cycle of products and limiting waste [25]. Although the European Circular Economy Package focuses mainly on waste, with the direct objective of revising directives on waste, landfill, packaging and end-of-life vehicles, but with little or no impact on the water sector, opportunities for the public water service -the third public service under consideration- can be relevant, such as reusing of water resources in industrial processes, reducing the withdrawal of natural surface and underground water resources, minimising environmental depletion [26].

Methods

Concerning the methodology, in this paper, the authors [27] consider the Data Envelopment Analysis (DEA) to assess the decision-making units (DMUs, the cities in the current research), showing the best practices compared to the entire set of observations. DEA is a mathematical programming approach used to measure the relative efficiency of DMUs, including radial and non-radial efficiency measurements, and it considers both input and output orientations [28]. DEA's adaptability and effectiveness have led to its widespread success since it represents an empirical technique that estimates relationships based on observable data that generalises the traditional input-output ratio analysis for efficiency evaluation and benchmarking. It calculates the efficiency of a production unit by computing the weighted sum of outputs divided by the weighted sum of inputs, with weights determined through constrained maximisation, eliminating the need for market prices. Efficient DMUs form the productivity frontier, while those scoring between 0 and 1 are inefficient, indicating potential improvements. In the present investigation, the input orientation appears more fitting because this is coherent with the assumption that public governments have more control over inputs than outputs, as suggested, among others, by Cook and Zho [29], assuming variable returns of scale.

Empirical analysis

As mentioned above, the article analyses the cost efficiency of cities used for local public services, as shown in Table 1. These three public services constitute the DEA inputs, and the expenditure committed for 2019 is considered for each of them. To develop the DEA model, the input variables are the cost of *Urban Waste Management* (X1), L*ocal Public Transport* (X3) and *Integrated Water Service* (X4); in addition, Waste Generation per inhabitant (X2) is included among the inputs as likely undesirable output [30]. The output variables are *Separate waste-collection* rate (Y1), *Passenger Public Transport* (Y2), *Urban Public Transport Offer* (Y3) and *Wastewater Purification Capacity* (Y4). Table 1 describes the input and output variables with descriptive statistics:

Table 3: Summary Statistics of Input and Output Sources: (1) ISPRA [31]; (2) LEGAMBIENTE [32] ; (3) BDAP [33].

Indicators	Source	Description	Min	Max	Mean	Median	STD
Input							
Urban waste management service (X1)	(1)	Committed Expenditure (Tot./nr. Ab.)	122.07	370.49	206.47	198.61	54.46
Waste Generation per inhabitant (X2)	(2)	Municipal waste generation (Kg/ab.)	11,688.43	1,691,887.32	129,020.41	62,389.50	242,898.17
Local public transport service (X3)	(3)	Committed Expenditure (Tot./nr. Ab.)	7.2	862.22	87.64	51.16	126.54
Integrated water cycle (X4)	(3)	Committed Expenditure (Tot./nr. Ab.)	6.36	9,969.91	1,511.31	803.04	2,123.33
Output							
Separate waste-collection rate (Y1)	(2)	% separate waste on total waste	0.16	0.87	0.59	0.62	0.18
Passenger Public Transport (Y2)	(2)	nr. journeys / habitants	5.94	704.52	103.42	59.53	124.9
Urban Public Transport Offer (Y3)	(2)	Distance (vehicle-km) /habitants	5.99	87.55	28.23	25.04	14.53
Wastewater Purification Capacity (Y4)	(2)	% residents served by urban sewage system	0.17	1	0.89	0.93	0.15

Using the RStudio software [34], the DEA is processed, which returns the results shown in Figure 1. The figure indicates that thirty-five cities (Aosta, Asti, Belluno, Bergamo, Bologna, Brescia, Caltanissetta, Como, Enna, Foggia, Genoa, La Spezia, L'Aquila, Lecco, Livorno, Lucca, Mantova, Milan, Modena, Naples, Novara, Parma, Pavia, Prato, Reggio Calabria, Reggio Emilia, Rome, Salerno, Siena, Teramo, Turin, Trento, Treviso, Venice, Vicenza) are on the efficient frontier. Several other cities operate relatively highly efficiently, such as Alessandria, Ascoli Piceno, Chieti, Ravenna, Rovigo, and Verona.

In this second-step analysis, the Super Efficiency DEA (SDEA, also known as SuperDEA) has been performed, as originally proposed by Andersen and Petersen [35]. In the SDEA, the reference set excludes the observed unit to obtain a new ranking of efficient units, thus making it possible to get a score >1. In this second step, the aim is to derive a ranking for efficient DMUs [36]. Table 2 shows the SDEA results.

Figure 5: DEA results Sources: Own processing on BDAP, ISPRA and Legambiente data

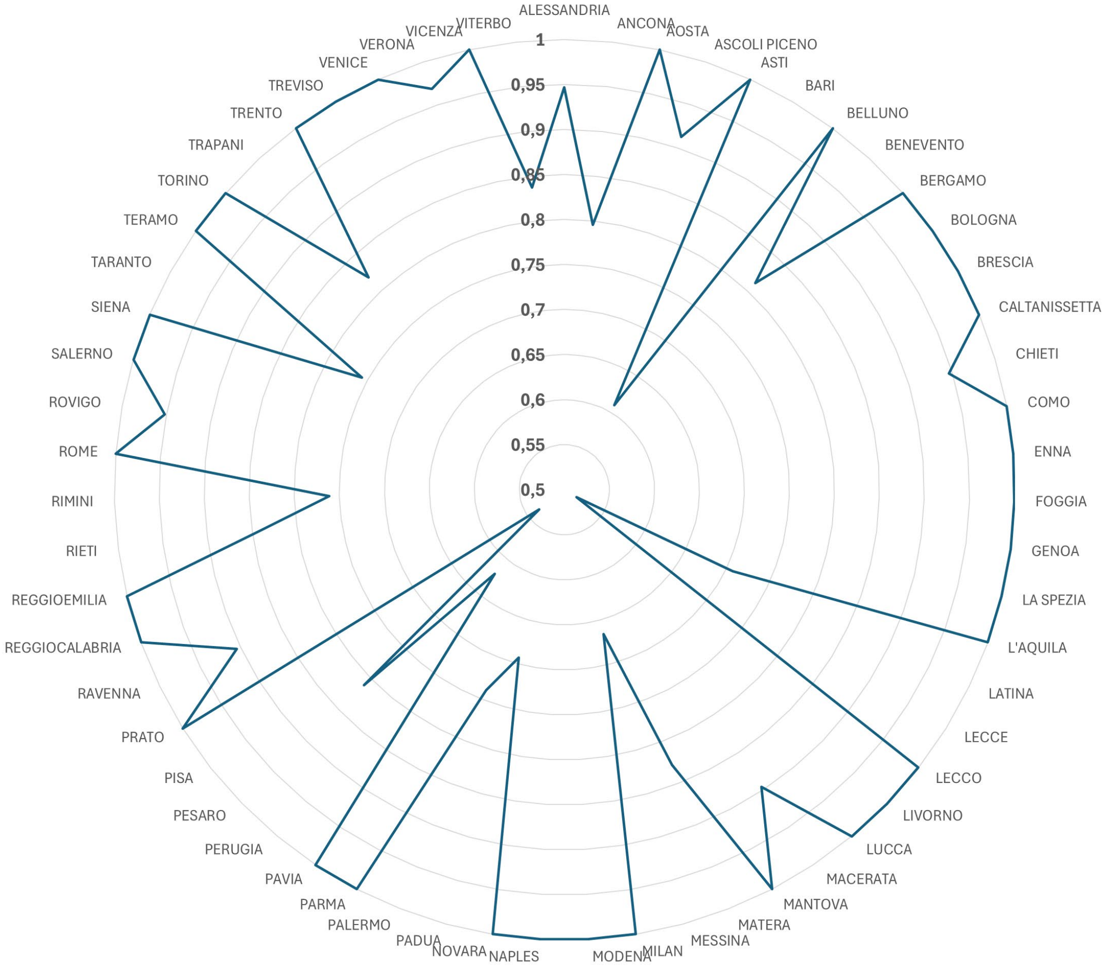

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Table 4: SuperDEA results *Sources: Own processing on BDAP, ISPRA and Legambiente data*

Città	SDEA	Città	SDEA	Città	SDEA	Città	SDEA	Città	SDEA	Città	SDEA	Città	SDEA
Parma	13.06	Reggio E.	2.96	Bologna	2.02	Siena	1.67	Teramo	1.52	Lucca	1.17	Brescia	1.03
Naples	8.92	L'aquila	2.87	Como	1.97	Salerno	1.59	Enna	1.34	Prato	1.16	Foggia	1.01
Turin	8.1	Lecco	2.48	Reggio C.	1.78	Pavia	1.55	Bergamo	1.24	Caltanissetta	1.1	Rome	1
Genoa	7.14	Modena	2.15	La Spezia	1.77	Vicenza	1.52	Asti	1.21	Novara	1.07		

Findings

Compared to the DEA results, which indicate the efficient cities that performed better in terms of the inputs and outputs used, the SDEA allows DMUs to obtain efficiency coefficients higher than 100%, with efficient cities that rank differently. In more detail, Parma stands out significantly, followed by Naples, Turin, and Genoa, indicating that policymakers might refer to the characteristics of large cities in order to improve their efficiency, though not all metropolitan cities rank highly. SuperDEA values decrease from Parma to Rome; this is the latest city in the ranking since it shows no incremental effect from its exclusion from the model. Nevertheless, in the SDEA approach, some cities suffer from infeasibility problems; therefore, they do not appear in Table 2, and the number of investigated cities decreases from 35 in the DEA analysis to 27 in

SuperDEA. Geographically, most cities in the SuperDEA ranking belong to Northern regions (55%), with Central and Southern Italy and the Islands represented by fewer cities. In general, SuperDEA provides a ranking that reveals the relative efficiency of cities, surpassing the qualitative criterion of geographic representation. Naples, a Southern city, ranks second with a significantly high score, surpassing several Northern cities. This finding indicates a more detailed efficiency ranking across different regions, though Central Italy is less represented. SuperDEA is more precise and indicative of efficiency levels than the DEA, as it quantifies efficiency levels effectively.

Discussion/Conclusion

In the current work, the results are based on a non-parametric approach based on variables determining urban efficiency, and these findings should be seen as a starting point for further analysis and guiding policy actions to improve public service planning. The main limitations of this study lie in the following main aspects. First, since the proposed methodological deterministic model considers the 'relative' inefficiency measures - and does not identify absolute efficiency - it evaluates the inefficiency considering the deviation from the frontier without considering any random disturbance. Secondly, the topic of the paper - the circular economy- presents several characteristics of novelty and complexity that require a broad discussion [37]. In addition, the statistical data quality suffers from some weaknesses, mainly due to the problematic availability of sources. Beyond these limitations, the paper's proposals could represent a concrete contribution to the research on methodologies for assessing the efficiency of public policies towards their continuous improvement. Understanding how efficiently cities spend on public services and how this can impact circular economy goals, today's fundamental paradigm of sustainability can help pursue national and supranational policy goals: central government could learn good practices that have shown some realities to be more efficient and spread them to other cities. The future development of this work could also expand the cluster of cities, involving different countries. In general, the authors believe that this present analysis might contribute to the construction of common indicators for urban areas, such as building common indicators to assess the impact of policies [38].

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Rheological analysis investigating the substitution of acrylic polymers in skincare products

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Abstract

As public attention on sustainability grows, in the cosmetic field the choice of raw materials in formulation processes is increasingly shifting toward natural alternatives, moving away from synthetic options. In this context, the physical-mechanical properties of two emulsions were studied through rheological investigation, which served as the foundation for the reformulation process. The selection of polysaccharides from a wide range of options was guided by the evaluation of the storage (G') and loss (G'') moduli of the initial benchmarks.
The results demonstrated that combining selected natural polymers in appropriate ratios can yield distinct and interesting rheological and textural properties. Moreover, this technique has been shown to be an effective pre-screening tool for the rational formulation of sustainable products.

Keywords: *Rheology; Polymers; Acrylates; Environmental impact; Ecologic transition.*

Introduction

Raising awareness on sustainability and circular economy is having consequences in all sectors [1].
In the cosmetics industry, this is evidenced by the growing demand for green products. Rheological modifiers, which play a crucial role in determining sensory and spreadable properties, are of particular interest. Acrylic polymers, derived from petroleum, are commonly used to enhance the textural properties of cosmetic formulations. However, the sustainability of acrylic polymers is under scrutiny, both considering their primary source, which is nonrenewable, and their nonbiodegradable nature. So, due to their environmental impact, efforts to replace them are underway [2].
Ecologic transition is a broad concept, that cannot be reduced to a single measure to be undertaken. Nonetheless, the predilection of natural raw material instead of synthetic ones is a promising approach to achieve the purpose. Just considering the huge amount of beauty-care products that are daily used by consumers, replacing the manufactured limits enormously the environmental contamination. Furthermore, is a step to reduce the reliance to fossil fuel, that nowadays is spreading widely.

The beauty care industry is driven by a strong emphasis on hedonism, where the sensory experience during and after product application is as important as functionality. To move beyond the trial-and-error approach, this study aims to establish an instrumental method that offers an objective and quantitative evaluation of qualitative parameters. In contrast to outdated methods, industries are increasingly seeking time- and cost-efficient procedures to achieve their desired outcomes [3,4].
In this study, two emulsions were selected for a reformulation process, with the goal of replacing the acrylic components in the formulas with a carefully chosen combination of natural polymers. Although synthetic polymers are engineered for specific performance, replicating their mechanical and sensory properties with natural alternatives can be challenging [5]. However, some natural gums have shown significant similarities to acrylic dispersions, making it possible to make informed choices in raw materials when redesigning formulations to replace blacklisted ingredients.

Methods and Materials

Five natural polymers were selected to lead the reformulation process.
Xanthan Gum. Bacterial fermentation origin, high molecular weight polysaccharide widely used in cosmetic formulation, both as rheological modifier and stabilizing agent, due to its pseudoplastic behavior [6].
Avicel. Cellulose complex, obtained by the combination of microcrystalline cellulose and cellulose gum, boasting suspending and structuring proprieties [7].
Sclerotium Gum. Biopolymer produced by glucose fermentation by molds. In presence of water, it leads the genesis of gel-like systems [8].
Succinoglycan. Bacterial origin anionic polymer. Pseudoplastic behavior, boost viscoelasticity of the formula in which it’s included [9].
Carrageenan. Red seaweeds origin. Due to the presence of sulfhydryl group, the polymer is slightly anionic, and requires cations to lead the jellification process. Furthermore, viscosity is strongly dependent on temperature: polymer need to be dispersed by heating, and the cooling process guarantee the formation of the tridimensional structure [10].
Hydroxypropyl Starch. Obtained by etherification of corn starch, providing a renewable and biodegradable polymer, with significant yield stress value [11].
Rheological analysis was performed using a Rheometer MCR-101, Anton Paar. Test were conducted at controlled temperature of 25°C, both in continuous and oscillatory flow conditions, using parallel plates with a fixed gate of 1 mm.
Flow properties were defined by continuous flow conditions, recording viscosity values by increasing shear rate, ranging from 0,001 to 1000 s^{-1}, due to define the shear thinning behavior of emulsions.
Viscoelastic behavior was investigated through oscillatory conditions. Amplitude Sweep test was performed by a fixed frequency of 1 Hz and increasing strain (γ), from 0,1 to

1000%, to study the linear viscoelastic region (LVR) and the critical strain (G'=G''). Moreover, Frequency Sweep was performed using fixed strain, which value was chosen within the LVR region, and increasing frequency from 10 to 0,01 Hz.

Findings

Formula one. The commercial gel-cream studied contains a significant amount of synthetic ingredients. Rheological analysis indicates that the product exhibits typical weak-gel behavior. In oscillatory tests, both the elastic (G') and viscous (G'') moduli fall between the second and third decades, with G' consistently greater than G'', although it remains below 10. Additionally, there is a slight dependence on frequency.
In the frequency sweep (Figure 1), the elastic modulus remains consistently greater than the viscous modulus. The two moduli display an almost parallel trend with slight frequency dependence, as indicated by a small decrease in the moduli with decreasing frequency.
Meanwhile, in the amplitude-dependent oscillatory analysis (Figure 2), attention is drawn to the cross-over of the moduli, which occurs at shear strain values greater than 100. Following this, the moduli gradually decrease, suggesting a smooth and creamy texture.

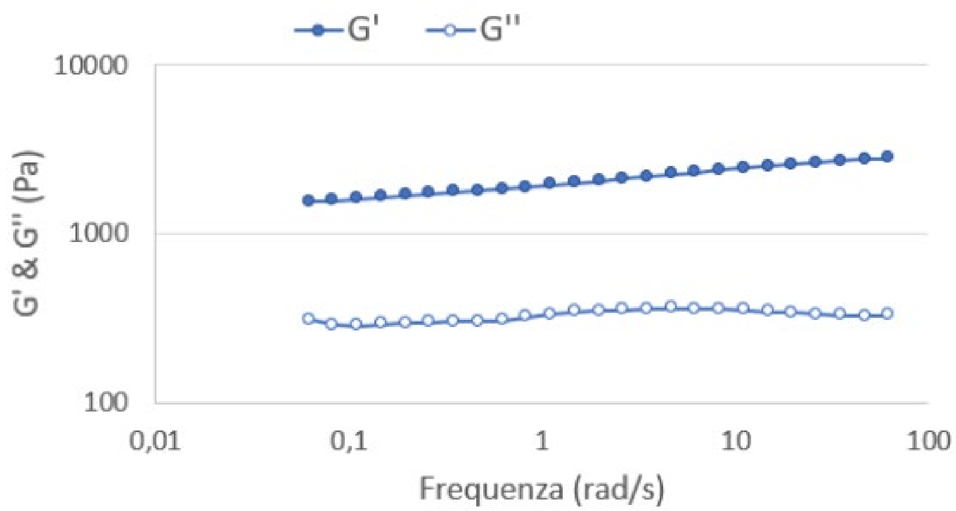

Figure 1. Formula 1, Benchmark, Frequency sweep

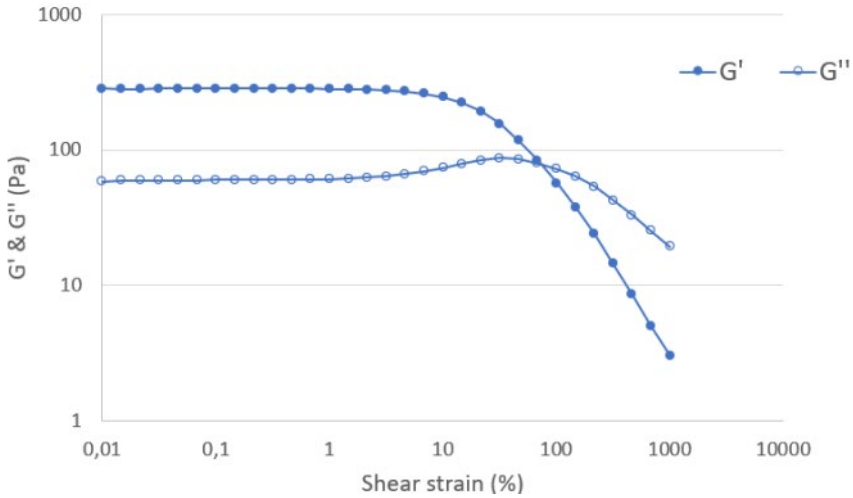

Figure 2. Formula 1, Benchmark, Amplitude sweep

Considering the rheological characteristics of the benchmark, the selection of raw materials focused on polymers that would create creamy, yet unstructured emulsions. Sclerotium gum, Succinoglycan, and Carrageenan were chosen, while Xanthan gum and Avicel, which were part of the original formula, were retained.

Formula two. The formula design was revised to anticipate potential reworking requests. Rheological analysis indicates a structured product: the frequency sweep (Figure 3) shows that the elastic modulus is consistently greater than the viscous modulus, with both running almost parallel. The amplitude sweep (Figure 4) reveals the cream's rigid and fragile texture, as evidenced by a drastic collapse of the elastic modulus at the end of the linear viscoelasticity range.

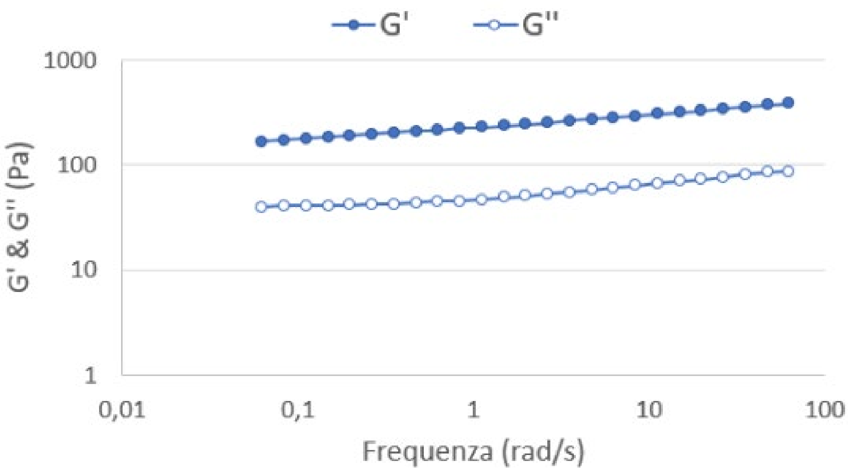

Figure 3. Formula 2, Benchmark, Frequency sweep

Given these observations, the selection of polymers to replace the acrylic component focused on polysaccharides capable of creating structured and resilient systems. Carrageenan and Hydroxypropyl Starch were chosen for this purpose.

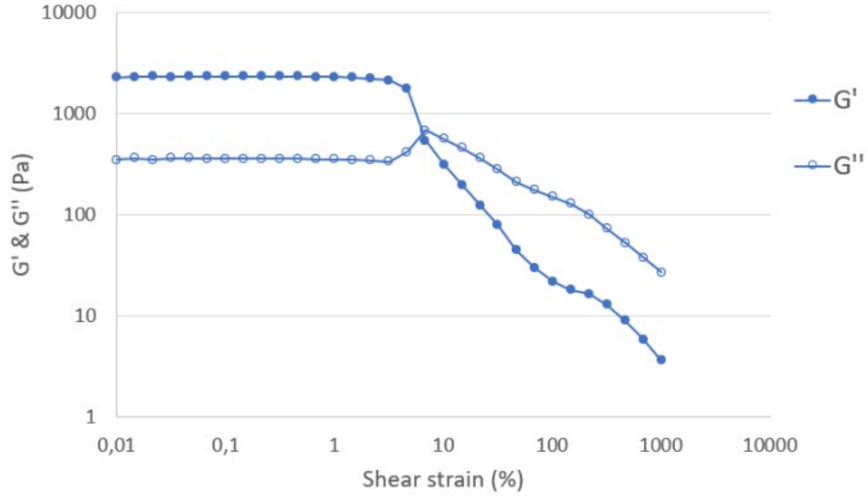

Figure 4. Formula 2, Benchmark, Amplitude sweep

Discussion

Formula one. Through the rework process, a large number of formulas were developed. The combinations of polysaccharides that yielded the most satisfactory results are listed in Table 1.

Table 1. Formula 1, percentage of rheological modifiers

	Sample 3	Sample 4	Sample 10	Sample 12
Avicel	1,50 %	1,50 %	1,50 %	1,50 %
Xanthan gum	0,30 %	0,30 %	0,30 %	0,30 %
Sclerotium gum	0,50 %	-	0,30 %	0,30 %
Succinoglycan	-	0,60 %	0,30 %	0,30 %
Carrageenan	-	-	-	0,10 %

The frequency sweep (Figure 5) reveals that all reformulated samples are less structured than the reference, although they maintain the frequency-dependent trend.
The investigation of viscoelastic properties as a function of oscillation amplitude (Figure 6) confirmis that all reformulated trials exhibit a Linear Viscoelastic Region (LVR), with strain at the intersection point and modulus trends comparable to those of the reference samples. Samples 3, 4, and 10 show nearly overlapping elastic and viscous moduli, while Sample 12 displays slightly higher structural characteristics, making it rheologically closer to the benchmark.

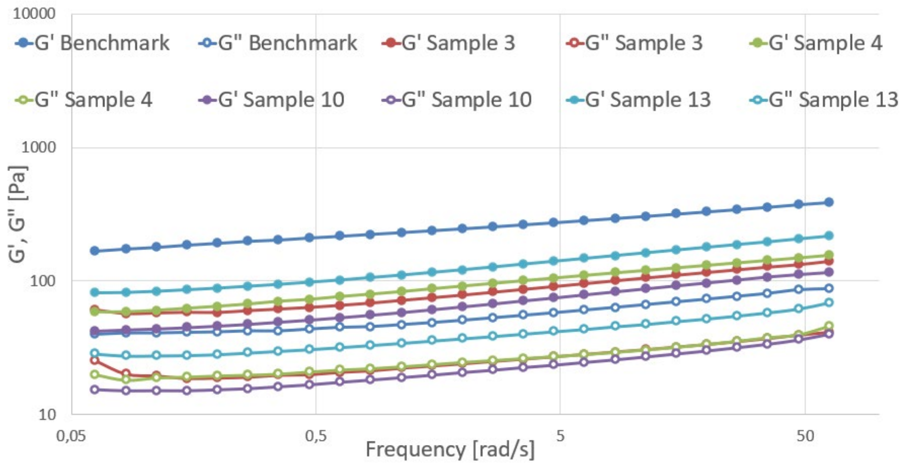

Figure 5. Formula 1, Frequency sweep

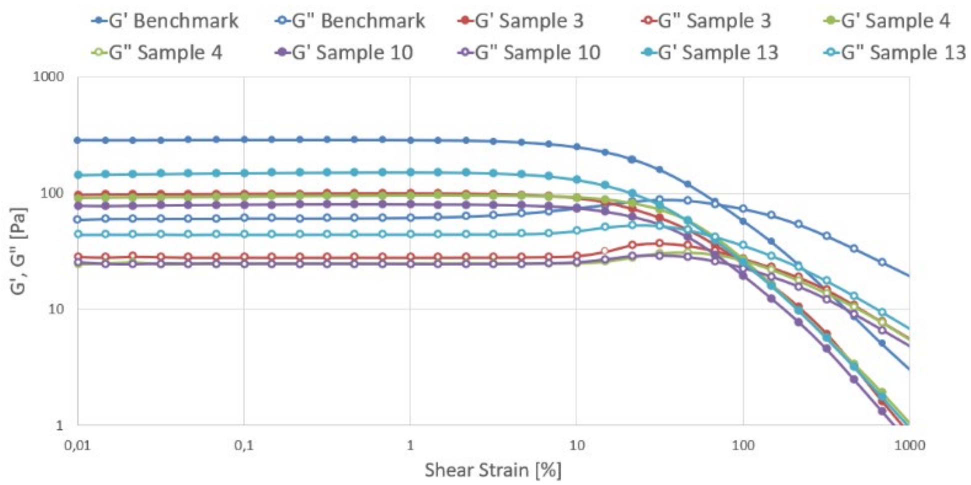

Figure 6. Formula 1, Amplitude sweep

Formula two. As stated before, reformulation process led to the development of many formulas, and the polysaccharides combination that pointed the most interesting results are listed in Table 2.

Table 2. Formula 2, percentage of rheological modifiers

	Sample 2	**Sample 3**	**Sample 6**
Hydroxypropyl Starch	1.50 %	-	1,50 %
Carrageenan	-	0,50 %	0,10 %

The investigation of the viscoelastic properties of the formulas, both in frequency (Figure 7) and amplitude sweep (Figure 8), indicates that Samples 2 and 3 exhibit elastic moduli very close to that of the reference, while having higher viscous moduli. In contrast, Sample 6 displays intermediate viscoelastic characteristics, where the slight reduction in elastic modulus is offset by an increased overlap of the viscous modulus.

Additionally, a notable difference in the intersection points of the moduli can be observed across all trials. Compared to the reference, Sample 3 has a lower critical strain, while Samples 2 and 6 show higher critical strains, suggesting that more shear is required for the viscous component to dominate and facilitate the flow of the sample.

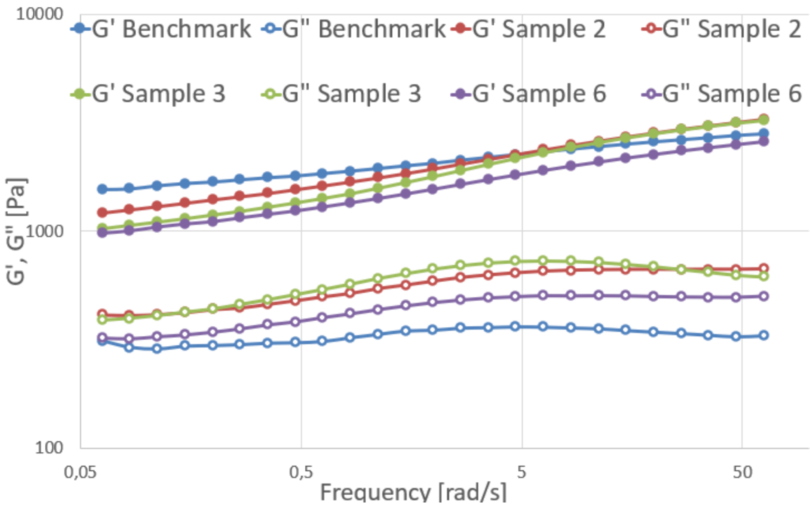

Figure 7. Formula 2, Frequency sweep

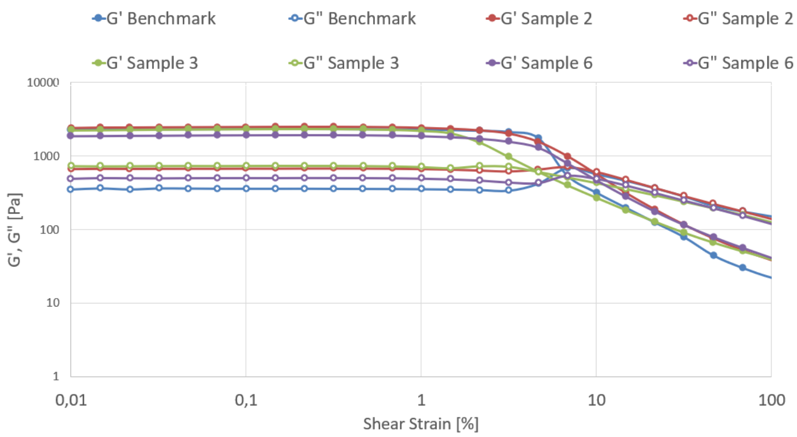

Figure 8. Formula 2, Amplitude sweep

Conclusion

The results of this study demonstrated that identifying the rheological properties of the initial benchmark is a valuable tool for selecting raw materials for the reformulation process. This approach has proven to be an effective protocol, despite reliance on empirical methods.

As anticipated, natural alternatives do not fully replicate the sensory and mechanical properties of synthetic polymers. However, the precise combination of different gums yielded a rheological profile closely aligned with that of the benchmark, marking a significant step toward ecological transition in the cosmetics industry.

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Q-BACKPAK: Customizable modular backpack

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Abstract

This thesis focuses on the design and development process of an innovative modular backpack, designed to meet the diverse needs of individuals engaged in various activities. As contemporary lifestyles evolve, modern individuals often find themselves involved in a diversified range of daily activities, spanning work-related tasks to recreational and sports contexts. The proposed backpack aims to address the adaptability to these situations through a modular approach, allowing users to customize the backpack based on specific needs, eliminating the need for different bags for each activity. The result is a backpack customizable in colors, appearance, and size, with a structure broken down into pouches that can also be used individually, as items that have their own purpose. This feature allows for the replacement of individual components of the backpack with different lifespans, without having to change the entire system, as would otherwise be the case with a common backpack. This way, the product's lifespan is extended, its use expanded, and the consumption of materials, space, and resources is reduced [1, 2, 3].

Keywords: *Backpack; Modularity; Multifunctional; System; Custom.*

Introduction

The user who engages in various activities often needs different backpacks for each one, which are excessively specialized, segmented, and targeted too specifically. These are designed with characteristics that are often limiting (shapes and volumes that are either too small or too large), requiring the purchase of backpacks with different appearances and features for almost every activity undertaken.
This equipment takes up space at home, is costly, and is not sustainable: often, even if we have a backpack with the right characteristics for more than one activity, if its appearance is not suitable for all of them, we prefer to buy an alternative one solely for its aesthetics.

Methods

The process began by collecting images of backpacks available in the market across relevant sectors to gain a comprehensive overview of the current state of the art. Subsequently, tables were created to compare the characteristics of these backpacks in terms of modularity, capacity, and aesthetic appearance. This approach allowed to compile a list of strengths and weaknesses characterizing the current state of the art, which was necessary to establish a research question and propose design ideas in response to it.

Keywords and references

The key concepts of the project are: Customization, Product System, Multi-Purpose, and Modularity.

Based on these, a search for design and aesthetic references was conducted to inspire the final characteristics of the project. The research included technical clothing [4] and sports equipment, but also architecture and product design projects, as well as visual elements from the world of art.

Aiming to be as realistic as possible considering the production phase, companies already offering products suitable for everyday use in various colors and materials were referenced. These materials were chosen based on careful considerations of sustainability, ease of disposal, and the lightweight and durable characteristics typical of a technical backpack.

Development and results

Starting with the ideation of some concept sketches, the process proceeded to create initial prototypes using scrap materials. These were essential to understand the limits and critical points of the various proposals. Through this extensive iterative phase, a detailed final concept was proposed: initial drafts of prototypes were created to understand the ergonomics, fit, and shapes, leading to the final prototype made with carefully chosen fabrics and hardware throughout all phases.

A significant phase was dedicated to selecting the attachments that secure the pouches to the back panels. It was crucial to find the right balance between lightness, ease of use, and ergonomics. The chosen hardware was inspired by military equipment, which has historically influenced technical clothing and sports gear. These attachments can also be easily replaced in case of breakage without needing to replace other parts with different lifespans.

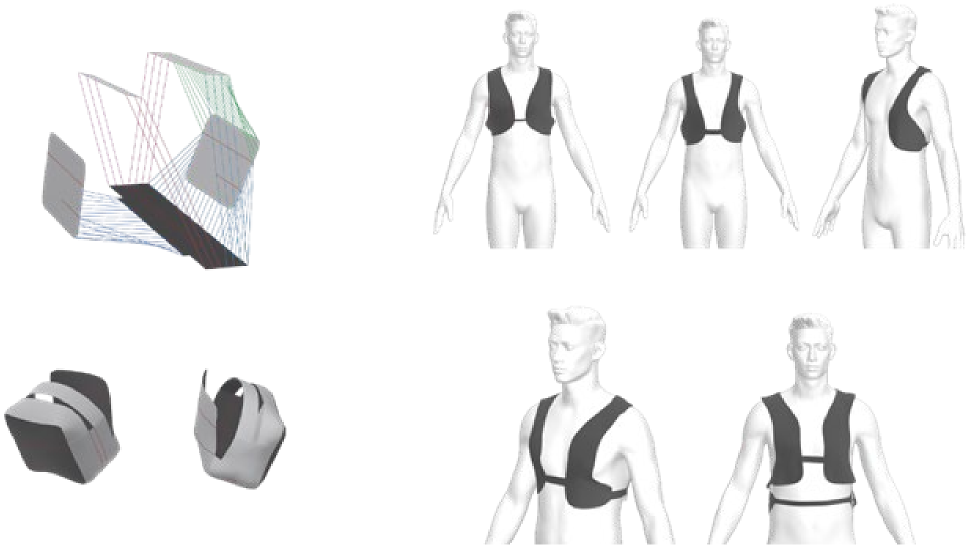

Figure 1. These two figures show the 3D models of the backpack's cubes (left) and shoulder straps (right) created using the Clo 3D software, which allowed for saving time and resources in researching the shapes and volumes of the Q-Backpack components.

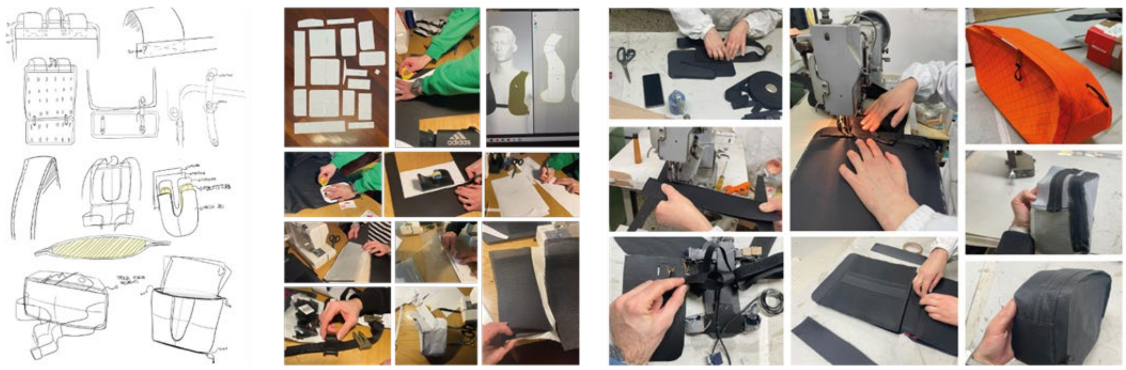

Figure 2: The following photos show the design phases: the concept sketches (left), the initial models and patterns independently created with scrap materials, the selection of hardware and other plastic components (middle), and the creation of the final prototype made in collaboration with professional tailors (right).

Figure 3. Three examples of possible configurations, each showing different objects that can be carried. The first configuration, a messenger bag, has a capacity of around six liters. The second offers a volume

of approximately twelve liters, while the third, ideal for longer trips, provides a capacity of about eighteen liters

Findings

The result is a backpack composed of back panels of various sizes to which different modules or pouches of diverse shapes and colors can be attached, much like an equipped wall. This design allows users to always carry the desired volume by selecting the appropriate back panel and attaching the necessary number of modules.
The need for such a project stems from the desire to offer customization in both size and aesthetic appearance for a product that typically lacks these features.
Like clothing, a backpack is considered as a part of an outfit, but, while owning multiple pieces of clothing or shoes is almost necessary, owning more than one backpack is less so, unless a specific product is needed for sporting activities. Having multiple backpacks can be wasteful in terms of the quantity of secondary goods accumulated and the space they occupy.
This proposal addresses this issue by saving vital living spaces through its design. The modules that make up the backpack can be used as containers for objects at home. These pouches are ready to be organized on the back panel when needed, thereby preventing unnecessary space occupation.

Conclusion

The project in question, as previously mentioned, does not aim to replace the use of technical equipment dedicated to specific activities, but rather to provide a sustainable alternative to using multiple backpacks for everyday activities. Regarding sustainability, the project has been designed with a medium- to long-term phase-out strategy in mind, considering products for which a deeper re-conception can begin today and that will eventually reach the end of their useful life in the medium- to long-term.
The laminated fabric used for the cubes is made from 100% recycled materials and is fully recyclable. Moreover, it is considered one of the most durable fabrics currently available on the market. It is crucial that this material does not deteriorate easily because, contrary to the belief that eco-friendly products made from easily disposable materials are more sustainable, they actually produce more pollution than long-lasting products.
The sustainability of the project is further enhanced by its inherent structure: the backpack is designed with elements that have varying lifespans, independent of each other. This allows for easy replacement of worn-out components independently, or even better, their reuse in other contexts as storage containers or organizers.
The project's limitations are related to ergonomics, which could certainly be further explored, and the distribution of the backpack's weight, which has only been

superficially considered to make room for the development of the innovative concept of its structure.

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Sustainability in the construction field: implementation of the "Circular economy" objective and the DNSH principle in the case study of a school building reconstruction

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Abstract
The work focuses on evaluating sustainability in the construction sector, particularly on applying the "Do No Significant Harm" (DNSH) principle in national projects funded by the Italian Resilience and Recovery Plan (PNRR). The methodology included an analysis of the main regulatory steps and guidelines that led to the creation of the DNSH principle and its application in construction, highlighting the lack of an operational procedure for consultants to demonstrate compliance with the principle. Therefore, the experimental part involved developing a proposed procedure for drafting the DNSH report through a case study on the demolition and reconstruction of a school. Additionally, the DNSH criterion on "Circular Economy" and the UNI/PdR 75:2020 standard, which defines a methodology for selective deconstruction and waste recovery, were investigated in detail. The case study provided the context for developing the methodology for DNSH reporting and for deriving an example of calculating the indicators useful for the Circular Economy.

Keywords: *Sustainable construction DNSH; Circular economy; Selective deconstruction; European Taxonomy.*

Introduction
In recent years, the urgency to address climate change, pandemic crises, and social and economic issues has led to a redefinition of the economic development model. Sustainability has become a crucial element for ensuring the long-term competitiveness of the European economy. Various policies, such as the European Green Deal [1] and the NextGeneration EU program [2], have highlighted the need for significant investments to transition towards a sustainable economy. The concept of sustainability has evolved to encompass not only the environmental dimension but also the social and economic ones. In this context, summarized in Figure 1, the concept of Sustainable Finance plays a significant role, conceived as a tool to establish a shift in investment evaluation criteria, increasingly directing them towards environmental and social sustainability objectives.

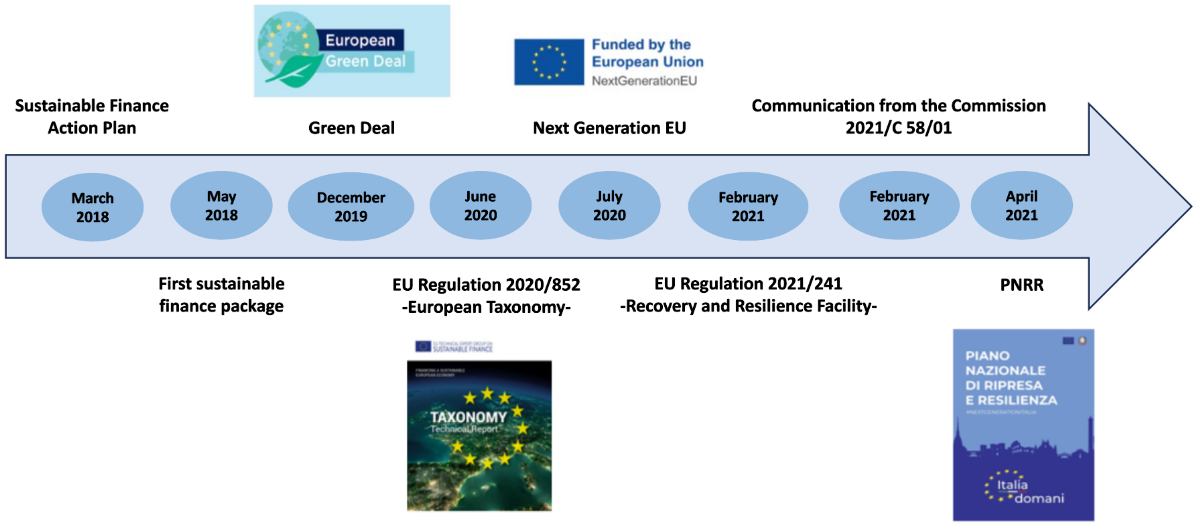

Figure 10. Timeline highlighting the key regulatory milestones that led to the establishment of the DNSH principle (Spinelli, 2024)

This shift has led to the adoption of new regulations and programs at the European level, including the "Do No Significant Harm" (DNSH) principle. The EU Regulation 2020/852 on the European Taxonomy [3], a classification system that establishes a list of environmentally sustainable economic activities, and the Next Generation EU program are fundamental in guiding this transition and defining the conditions under which an economic activity respects the DNSH principle. However, it has been noticed that an operational procedure for consultants to demonstrate compliance with the DNSH principle of construction projects funded under the PNRR program was missing. Therefore, the objective of this work was to develop an operational procedure, in collaboration with Nexteco srl, to assess compliance with the "Do No Significant Harm" (DNSH) principle in the construction sector, with particular attention to projects funded by the National Recovery and Resilience Plan (PNRR). The case study of a school building reconstruction was chosen because the renovation of school buildings is a typical example of interventions that have been selected and financed with PNNR funds, therefore it can provide a useful path for similar projects.

The construction sector exerts significant pressure on various environmental components and, overall, has a substantial impact. For instance, the construction industry globally accounts for 37% of carbon dioxide emissions and represents over 34% of global energy demand [4]. The environmental impact of construction is not limited to energy consumption and carbon dioxide emissions; it also involves consequences for the ecosystems, such as land and resource consumption, including water and raw materials, which are known for their scarcity. Additionally, it is important to consider the environmental effects resulting from the extraction, processing, and transportation of construction materials, which, at the end of their life cycle, must be disposed of as waste if they cannot be recycled.

Methods

DNSH principle

The DNSH principle, which must be respected by every intervention funded under the PNRR, aims to ensure that no intervention causes significant harm to the six environmental objectives outlined in the European Taxonomy (Table 1).

Table 13. This table outlines the conditions under which an economic activity may cause significant harm for each of the six environmental objectives of the EU Taxonomy (Spinelli,2024).

Environmental objectives	It causes harm if:
Climate Change Mitigation	The activity leads to significant greenhouse gas emissions
Climate Change Adaptation	The activity worsens the negative effects of current and predicted future climates on itself, people, or nature.
Sustainable Use and Protection of Water and Marine Resources	The activity harms the good status or potential ecological status of water bodies, including surface and groundwater, or the ecological health of marine waters.
Circular Economy	- The activity results in significant inefficiencies in the use of materials or in the direct or indirect use of natural resources at one or more stages of the product life cycle, including durability, repairability, upgradability, reusability, or recyclability of products. - The activity leads to a significant increase in waste production, incineration, or disposal, except for the incineration of non-recyclable hazardous waste or the long-term disposal of waste that could cause significant and long-term harm to the environment.
Pollution Prevention and Reduction	The activity causes a significant increase in emissions of pollutants into the air, water, or soil compared to the situation before it began.
Protection and Restoration of Biodiversity and Ecosystems	The activity significantly harms the good condition and resilience of ecosystems or damages the conservation status of habitats and species, including those of interest to the Union.

The Italian Ministry of Economy and Finance issued an operational guide [5] to support administrations and implementing entities in demonstrating compliance with the DNSH principle, providing verification criteria to facilitate this process. This guide [6] is structured into the following sections: Mapping or correlation matrix; Self-Assessment Forms; Technical Sheets; Verification and Control Checklists; Appendix for the climate change adaptation objective.

Proposal of a Procedure to Evaluate the Compliance with the DNSH Principle of a new project

For projects funded by the PNRR, it is necessary to demonstrate compliance with the DNSH principle through a series of documents and reports related to various aspects of the design and execution of the construction intervention. The proposed procedure consists of four main phases:

1. **Brief Description of the Intervention**: A short description based on the documentation provided by the client;
2. **Contextualization of the Intervention**: Definition of the PNRR "mission" that the intervention refers to and classification of the so called "regime";
3. **Analysis of DNSH Evaluation Forms**: Identification of the forms relevant to the intervention;
4. **Verification of DNSH Compliance**: Assessment of the intervention against the six environmental objectives (mitigation to climate change, adaptation to climate change, sustainable use of water and marine resources, circular economy, pollution prevention, and protection of biodiversity) through ex-ante and ex-post verification elements.

Circular Economy

In the case study, special attention has been paid to the objective of the circular economy. To comply with the DNSH principle, this objective must demonstrate, through ex-ante and ex-post verification, that at least 70% of non-hazardous construction and demolition waste is directed towards reuse, recycling, or recovery. This requirement is met by adhering to Criterion 2.6.2 of the Minimum Environmental Criteria (CAM) for construction [6]. Additionally, it is important to follow Criterion 2.4.14, which establishes that at least 70% of construction materials must be disassemblable or selectively demolishable to enable reuse or recycling. The ex-ante verification includes checking the waste management plan and the deconstruction and end-of-life plan in accordance with CAM (Ministry of Ecological Transition, 2022). The Executive Project for Selective Demolition under development includes the quantities listed in Table 2, already grouped into homogeneous categories with assigned weights in kg and CER codes (based on the European Waste Catalogue).

Table 2. List of materials from selective demolition for the case-study, associated CER codes and weight in kg, and the end-of-life destination (Executive Project, 2024).

MATERIAL	CER	DESCRIPTION CER	Weight (kg)	Destination
Concrete	170101	cement	1.631.400,00	Recovery
Brick	170102	bricks	476.100,00	Recovery
Reinforced concrete	170107	Mixtures or separate fractions of cement, bricks, tiles, and ceramics, other than those mentioned in entry 17 01 06*	2.444.800,00	Recovery
Screed	170101	cement	161.560,00	Recovery
Ceramic	170103	Tiles and ceramics	74.280,00	Recovery
Linoleum	170203	plastic	1.300,00	Recovery
XPS-EPS	170604	Insulating materials other than those mentioned in entries 17 06 01* and 17 06 03*	3.902,50	Disposal
Copper	170401	copper, bronze, brass	8.188,00	Recovery
Bituminous membrane	170302	*Bituminous mixtures other than those listed in entry 17 03 01**	1.280,00	Disposal
Sand-Coated Bituminous Membrane	170302	*Bituminous mixtures other than those listed in entry 17 03 01**	3.940,00	Disposal
Glass	170202	glass	587,50	Recovery
Wood	170201	wood	51.000,00	Recovery
Steel	170405	Iron and steel	2.700,00	Recovery
			4.861.038,00	

Once the respective CER codes were assigned, the final phase involved calculating the percentage of materials that will be recovered (%R) or disposed of (%D). To do this, first, the weight of the waste directed to recovery and the weight of the waste directed to disposal were calculated. Then, by relating these weights to the total weight of the waste, %R and %D were determined (Table 3, line A).

Table 3. Ex-ante (A) and ex-post (B) percentage of materials destined for recovery or disposal (Spinelli, 2024)

A	Recovery	99,8%
	Disposal	0,2%
B	Recovery	93%
	Disposal	7%

Overall, therefore, subject to further analytical checks to be carried out during the construction work, it appears that almost all of the waste can be directed towards recovery operations. Additionally, having estimated a recovery rate of 99.8%, it has been amply demonstrated, at least hypothetically, that the Circular Economy requirement is met. Subsequently, this percentage was confirmed during the ex-post verification phase. Specifically, a hypothetical example was constructed with "simulated data" from which it was possible to calculate the percentage of demolition waste that will go to recovery, necessary to confirm the estimate made in the ex-ante phase. Therefore, recalling that the percentages reported in Table 2 (line B) are based on hypothetical data, an ex-post recovery rate of 93% is expected. Although this percentage is lower than the one estimated in the ex-ante phase, it still meets the 70% requirement imposed by the Circular Economy objective.

Results

Nowadays, construction and demolition materials, in order to be considered recycled and therefore secondary raw materials, must meet the criteria established by the Ministry of the Environment Circular No. 5205 of 2005 [8] and the recent Regulation of the Ministry of Ecological Transition No. 152 of 2022, known as "End of Waste" [9]. This regulation defines the conditions under which construction and demolition waste ceases to be considered as such. According to the ISPRA data from the 2023 Special Waste Report [10], in 2021 the recovery rate of demolition waste was 80.1%, exceeding the 70% target set by Directive 2008/98/EC for 2020 [11] and reiterated in the CAM for construction and the technical sheets of the Operational Guide for the DNSH principle. Despite the increase in the recovery rate, the main challenge lies in the circularity rate. Recycled materials are transformed into products but struggle to find market outlets, despite the abundant supply. It is crucial to incentivize prevention, reuse, and recycling, as specified in Article 13 of the European Taxonomy. This would increase the competitiveness of secondary raw materials (SRMs), reduce storage in plants, and prevent saturation and blockage of the construction supply chain. In particular, concerning the market for construction and demolition waste in Europe, it is found that recycled aggregates are largely destined for low-quality recovery and use, for example, in road sub-bases or in the production of sand, concrete, cement, ceramics, bricks, and low-cost adsorbents for wastewater treatment. To improve the quality of this waste and consequently increase its market, the potential measures proposed by the European Environment Agency [12] come to aid. Specifically, it is suggested to use selective demolition methods (such as the new UNI/PdR 75:2020 [13]) which also ensure greater separation into homogeneous streams at the source.

Discussion and Conclusion

The objective of the thesis was to develop an operational procedure to assess compliance with the "Do No Significant Harm" (DNSH) principle in the construction sector, with particular attention to projects funded by the National Recovery and

Resilience Plan (PNRR). In collaboration with Nexteco srl, the demolition and reconstruction of a school was analyzed. The analysis highlighted that the Operational Guide from the Ministry of Economy and Finance provides sufficient guidelines for meeting the six environmental objectives of the DNSH principle but lacks details on integrating the Minimum Environmental Criteria (CAM). The thesis work described in this paper proposed an operational procedure, illustrating how the DNSH report and the CAM report can support compliance with the European Taxonomy. The methodology included a regulatory analysis and the assessment of the DNSH principle applied to the case study. Furthermore, the "Circular Economy" criterion was explored, evaluating the UNI/PdR 75:2020 methodology for selective deconstruction and waste recovery, highlighting regulatory complexities and the need for tools that ensure a market for secondary products. The proposed approach demonstrated the importance of systematizing information related to construction interventions and adopting measures to minimize environmental impacts, thus supporting and promoting sustainability in the construction sector. The results obtained in the case study can be generalised, especially in terms of procedure, for similar cases that involve the use of selective demolition. This approach allows to improve performances by generating high quality waste already divided upstream into homogeneous categories, thus demonstrating the conformity of the project to the requirements of the Circular Economy objectives.

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ENERGY

Analysis of circularity in the industrial sector and enhancement strategies through renewable energy sources

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Abstract

This case study proposes a strategy for the improvement of the circularity policy in the industrial group GARC through the examination of the logistics. The replacement of the current fleet with electric and hybrid vehicles in a 20-year span has been examined to achieve the proposed objective and the analysis includes the design of a photovoltaic plant useful to satisfy the energy demand. The measurement of the industrial circularity follows a technical procedure published by the national standards association while for the electrification of the fleet have been considered among the other things the daily use of the vehicles, the technical feasibility and the economic investment.

Keywords: *Circular Economy; Electric vehicles; Photovoltaic energy.*

Introduction

The need to develop a new economic system that considers the limitation of resources and the necessity to recover what has been used arose in the 1960s [1]but it is only in the last decade that this issue has become central to international policies [2, 3]. Due to its membership to the EU Italy had to conform to the legislation [4] and moreover it was the first member country to publish a specific technical standard for measuring organizations' circularity.

The standard describes a calculation procedure based on the measurement of a set of indicators identified in such a way as to provide the most complete possible description of the company, thus guaranteeing a holistic approach to measurement. The proposed set of indicators is the basis of a calculation matrix designed to be an easily compilable, intuitive, and adaptable tool for different types of users. The holistic approach of the matrix links the indicators to each other, so among the possible interventions to improve circularity, it was decided to explore those related to logistics and more specifically the possibility of electrifying the industrial group's fleet.

The feasibility study of the replacement process corresponded to a long-term simulation in which technical, ecological, and environmental factors were considered, and different scenarios were developed based on these. The in-depth analysis of the logistics sector allowed for a more detailed understanding of the characteristics and use of the vehicles in use, broadening the perspective on company management.

The need to adapt the expected electrical consumption to the current infrastructure provided the opportunity to study a new photovoltaic system that could partially or completely meet the power required by the new vehicle fleet. This system was designed not only by utilizing the available covers on the property but also by using new structures in the parking lots already set up for the connection of charging points for vehicles.

Methods

Analysis of the circularity

The circularity level measurement proposed in the technical specification is based on a rating system that uses three types of indicators that are quantitative, qualitative and semiquantitative. For the first type the assigned value is between 0 and 1, for the second the value is 0 or 1 when negative or positive and for the last type are used threshold values. The indicators are grouped into 6 categories and the circularity level is calculated for each of them and for the overall level according to the underlying equation, proposed by the same standard and filled in with the values of the utilized indicators.

$$LC = \frac{\sum_{l=1}^{n} c_l + \sum_{j=1}^{m} s_j + 0{,}5 \sum_{k=1}^{f} p_k}{c+s}\ x\ 100$$

“c” the number of applicable “core” indicators and $C \subset N$ the ordered set of C: {1, 2, ..., c - 1, c}; “n” is the number of “core” indicators used.

“s” the number of applicable “specific” indicators and $S \subset N$ the ordered set of S: {1, 2, ..., s - 1, s}; “m” is the number of specific indicators to be completed and must be at least half of those available for compiling.

“p” the number of applicable “rewarding” indicators and $P \subset N$ the ordered set of P: {1, 2, ..., p - 1, p}; “f” is the number of “rewarding” indicators used.

The result of the calculation is a percentage value from 0 to 100% and there is no minimum target value for a positive outlook. The letters used are referred respectively to the three types of indicators: core, specific and rewarding ones. The compiler must consider all the “core” indicators available and when it is not possible to fulfil them the assigned value is 0. At least half of the “specific” ones must be compiled, otherwise the lacking indicators will be valued as 0. The compilation of the last type of indicators is not a commitment but is rewarded adding their values to the numerator, even though the sum of them is halved. The indicators are 71 but the compiler has not to fulfil all of them. This technical specification does not provide a tool, so the first step in the measurement process was to create a prototype calculation matrix, subsequently updated by comparing the required data with the insertion methods. The results provided by the

matrix quickly made it possible to identify the indicators that could be improved, and by defining a hierarchy of feasibility and effectiveness, some strategies were proposed to improve this score. The matrix was developed considering the obligations and compilation methods, but also keeping in mind that it should be an intuitive, effective and recompilable tool. First, the type of organization must be defined, and then the time and space parameters.
The industrial group being measured provides services in the construction (GARC S.p.A.) and environmental sector (GARC Ambiente S.p.A.), therefore it's a service industrial group. The measurements were made with reference to 2022 data considering both the headquarters and operating units on the national territory. Given the amount of data it was decided to proceed by applying threshold values, especially to the total incoming supplies at each construction site and headquarters. This procedure didn't affect the quality of the data considering that for both companies more than 85% of the supplies of goods and services were maintained. Similar study and data distinction approaches were also applied to the remaining indicators to work on a smaller but still highly representative amount of data.

Vehicle fleet design criteria

The industrial group's logistics office provided data on vehicles such as model, engine type, ownership, mileage, fuel consumption, maintenance, and for non-owned vehicles the start and end dates of leasing contracts.
The initial vehicle data was divided into macro-categories (passenger cars and commercial vehicles) and then into segments. For passenger cars were used the categories B and C of the unofficial Euro Car segment while the commercial vehicles were divided between transport of people or supplies (above or below 2 tonnes). The result is a five-categorization system, and this approach is fundamental for simulating as realistically as possible. The decision-making process that guided the replacement strategy is based on a comparison between the use of the vehicles and their relative consumption, the difference in purchase, rental and maintenance costs between ICE (internal combustion engine), BEV (battery electric vehicles) and hybrid vehicles, the market offers and the impact on the existing electrical infrastructure (costs and loads).

The next step was to develop replacement methods for the period 2024-2045, defining three periods:

- First period (2024-2029): The number and characteristics of vehicles with expiring rental and leasing contracts are known. In addition to the vehicles in use, those that will potentially increase the fleets have also been estimated, based on the trend in previous years.
- Second period (2030-2035): The vehicle replacement rate and fleet growth follow the methodologies of the first period. To estimate the growth of the vehicles in each category, their distribution compared to the 2024 data (in line

with that of 2022 and 2023) was calculated and maintained unchanged in subsequent years. The decision to study the period up to 2035 is due to current European and national regulations that set 2036 as the deadline to produce new internal combustion engine and hybrid (plug-in, PHEV - full hybrid, MHEV - mild hybrid) vehicles.

– Third period (2036-2045): Even after the regulations come into force, the vehicles affected will still be allowed to circulate, so they have been kept in the simulation. The expected changes follow the calculation methods of the previous period.

The second part of the study focused on charging methods. The daily absorbed power was calculated by defining a rotation of use and based on this, identifying the number of vehicles in charge. Calculating the power required for the transition is essential to design a new photovoltaic system that can at least partially cover this demand but also to assess how the demand for electricity needed by companies will change.

The third phase of the study addressed the economic calculation, distinguished by vehicle ownership (owned and rented), fuel cost, ordinary maintenance cost, and insurance and stamp duty costs. To make the time variation more realistic, a growth or contraction of vehicle costs was estimated on a five-year basis in relation to their engine type, based on current data and trends.

Finally, the emission reductions were quantified, starting with those avoided in the 2024-2029 five-year period. By calculating the tons of carbon dioxide saved by each electric vehicle compared to the number of electric vehicles present in each year, the emission reduction was calculated as a weighted average; this average value was then multiplied by the years after 2029 for which the BEV vehicles of each year are known. To assess the correctness of this calculation method, the years 2035, 2040, and 2045 were taken and the emission reduction was calculated using an alternative method: knowing the number of passenger cars and commercial vehicles, reference vehicle-engine classes were used and the emissions for each of them were calculated based on the mileage data. In this way, the analysis became more precise and the difference between the tons emitted by internal combustion engines alone and those contained or avoided by hybrid or electric counterparts resulted in the CO_2 reduction. The emissions calculated in this way were compared with those estimated according to the weighted average and it was observed that for all three reference years the average gave an underestimated value (the difference is <10%) that tends to coincide with the other the greater the number of vehicles involved.

Photovoltaic plant design

The estimation of the average annual consumption of the potential fleet provided a reference base for the design of the photovoltaic system. This system is composed of multiple units called "sub-systems" and located partly on the double-pitched roof of the warehouse and partly by installing the modules on shading structures for the vehicles. The design started from the available free surface data and the characteristics of the RECOM 710 modules. The data from the atlas [5] drawn up by ENEA were used for the productivity of the photovoltaic system, while the loss due to shading was calculated with the S.O.L.E. software [6]. For each of the sub-systems, the irradiation data were calculated with respect to the different inclination and the presence of obstacles. In the testing phase following the design, COLLADAURE software [7] was used and, as in the previous case, the strings for the individual sub-systems were tested. The system thus designed is composed of 290 modules and has an installed power of 206 kWp, capable of producing 220 MWh in the first year. Once the sub-systems have been tested, it is possible to simulate the operation until 2045 using the SIMULARE software [8]. The consumption entered the simulation is equal to the sum of the consumption of the vehicle fleet and that of the headquarters itself. This sum was structured respecting the distribution of the consumption of both inputs in such a way as to have the most objective economic calculation possible. The last part of the design concerns precisely the economic aspect, in which the prices of the energy cost, of the self-consumed and injected into the grid quotas, of the execution of the works and of the maintenance were considered.

Findings

The results of the circular analysis for the organizations are 56.72% for GARC S.p.A. and 56.39% for GARC Ambiente S.p.A.

If the impacts of this study were to be considered in the aforementioned indices, there would be an increase in the level of circularity for both companies: GARC SpA 57.86% (+1.06%) and GARC Ambiente SpA 58.40% (+2.00%).

As for the fleet electrification, the three scenarios considered in the simulation demonstrated the effectiveness in terms of direct emission reduction and economic feasibility. Although economically disadvantageous in the short term (2024-2029), the balance between cost increase and emission reduction is still very favorable for the latter. In fact, a cost increase of <15% (+14.00% for GARC S.p.A., +10.20% for GARC Ambiente S.p.A.) corresponds to an emission reduction of >30% (-41.80% for GARC S.p.A., -35.10% for GARC Ambiente S.p.A.); in the long term, the possible replacement of vehicles would be economically more advantageous preferable than maintaining an internal combustion fleet. In environmental terms, the emission reduction can be quantified in over 8,300 tonnes of CO_2 in 20 years (6,209 tonnes CO_2 for GARC S.p.A. and 2,092 tonnes CO_2 for GARC Ambiente S.p.A.).

The possible associated plant would be able to cover 38% of consumption in the first two years and 10% of the expected consumption in 2045. The consumption coverage is markedly decreasing since it goes from 342 MWh in 2025 to 1,928 MWh in 2045, largely due to the electric fleet.

Conclusion

In the presented case study, the main difficulties for measurement concerned the analysis of material and logistical flows in the various construction sites. This means that the proposed measurement methodology, although designed to be applicable to all types of industry, should consider the operating methods of companies with multiple operating sites. The usefulness of measurement is nevertheless high, both in terms of gaining a better understanding of industrial processes and developing objectively valid strategies.

The logistical approach is one of those identified through an analysis of the measurement results and the definition of a hierarchy of improvement strategies, including those related to water management or incoming recycled products. Compared to other strategies, however, it is the only one that concerns both direct emissions and the possibility of increasing the share of renewables, showing the underlying correlations between decision-making processes and impacts.

As reported in the specification itself, it is therefore a very useful product, but it needs to be revised.

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Taking action on adaptation to climate change: renewable energy communities and carbon credits, between regulation and open challenges

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Abstract

Climate change is one of the most pressing challenges of our time, requiring urgent collective action to mitigate its effects. This work focuses on actively participating in climate change adaptation, exploring the world of renewable energy communities and carbon credits, between regulation and open challenges. First, the energy transition in the context of the environment and climate change is examined. Subsequently, the regulatory framework of energy communities is addressed, with an analysis of the European and Italian regulations. Finally, we will close the loop by exploring some decarbonization tools, such as carbon credits and CO_2 savings in renewable energy, discussed in relation to the decarbonization targets set out in international climate agreements. The work aims to provide an in-depth understanding of the challenges and opportunities associated with adaptation to climate change with the use of renewable energy communities and carbon credits.

Keywords: *Renewable energy communities; Decarbonization; Sustainbility; Carbon credits; Environmental law.*

Introduction

Renewable Energy Communities (RECs) have emerged as pivotal elements in the transition toward a more sustainable and decentralized energy system. Defined by the EU's Renewable Energy Directive (RED II) as groups of citizens, small and medium-sized enterprises (SMEs), or local authorities who cooperate to produce, consume, and manage energy [1], RECs represent a significant shift toward localized energy governance. This study aims to provide an in-depth analysis of the legal frameworks that facilitate the formation and operation of RECs in Italy, drawing on both EU directives and national legislation. The urgency of climate change necessitates innovative solutions that go beyond traditional energy models. RECs offer a promising avenue by integrating renewable energy sources at the community level, thus enhancing energy security, promoting social inclusion, and driving economic benefits.

Methods

This study employs a multidisciplinary approach, integrating research on legal and scientific databases and subsequent analysis with technical and economic perspectives. Primary sources include EU directives, national regulations, and case law. Secondary sources encompass academic literature, policy reports, and industry analyses. The research methodology involves a detailed examination of legal texts, complemented by case studies of existing RECs in Europe to identify practical challenges and best practices. The research methodology was conducted in several stages. First, EU directives, national regulations, and relevant case law were reviewed to establish the legal frameworks governing RECs. Sources were selected based on their relevance to current regulatory practices and their applicability to the Italian context. Next, academic literature, policy reports, and industry analyses were analyzed to gain insights into the technical and economic implications of RECs. The examination process involved detailed analysis of legal texts, supported by case studies of existing RECs across Europe, which were chosen based on criteria such as their scale, governance structure, and operational outcomes. This method allowed to identify both practical challenges and best practices, which are crucial for understanding the potential of RECs in driving energy transition.

Findings

European Union Regulatory Framework

The European Union has been a global leader in promoting renewable energy through comprehensive policy frameworks. The "Clean Energy for All Europeans" package, introduced in 2016, is a cornerstone of the EU's effort to transition to sustainable energy systems. This package includes several directives, notably the Renewable Energy Directive (EU) 2018/2001 (RED II) and the Electricity Directive (EU) 2019/944, which collectively mandate member states to facilitate the establishment and operation of RECs.

RED II is particularly significant as it requires member states to create enabling frameworks for RECs, ensuring that citizens and local entities can participate in renewable energy projects. The directive sets ambitious targets for renewable energy production, aiming for at least 32% of the EU's energy consumption to come from renewable sources by 2030 [2]. It emphasizes the role of RECs in achieving these targets by promoting self-consumption and energy sharing.

Italian Legislative Landscape

Italy has proactively responded to EU mandates by enacting several laws that support the development of RECs. The Legislative Decree No. 199 of November 8, 2021, which transposes the RED II into national law, serves as the backbone of Italy's regulatory framework for RECs. This decree outlines detailed criteria for the establishment and operation of RECs, including governance structures, operational guidelines, and incentives for renewable energy production.

In addition to the Legislative Decree, other significant legal instruments include the Milleproroghe Decree (Decree-Law No. 162/2019) and subsequent amendments, which introduced experimental configurations for collective self-consumption and energy sharing within RECs. These regulations aim to simplify the administrative processes involved in setting up RECs and provide financial incentives such as feed-in tariffs and tax breaks.

However, the implementation of these laws faces several challenges, such as bureaucratic hurdles, financial constraints, and the need for technical expertise. The varying definitions and membership criteria for RECs across different regions add to the complexity, leading to legal uncertainties and operational difficulties.

Strategic Role of Renewable Energy Communities

RECs are strategically important for achieving Italy’s and Europe’s energy transition goals. By enabling local production and consumption of renewable energy, RECs reduce dependence on fossil fuels, lower greenhouse gas emissions, and enhance energy resilience [3]. They also foster community engagement and economic development by allowing citizens to actively participate in the energy market.

The potential of RECs is significant, with an estimated 11 GW capacity, which could increase to 17.2 GW by 2030 through full implementation of EU Directive 2018/2001 [4]. This expansion could generate an additional 22.8 TWh of renewable energy, contributing 30% toward the targets set by Italy's National Energy and Climate Plan (PNIEC) [5]. Economically, the adoption of RECs could add approximately €2.2 billion in value to the renewable energy sector, boost tax revenues by €1.1 billion, and create around 19,000 jobs by 2030 [6].

Moreover, RECs could reduce CO_2 emissions by 1.35 million tonnes, offering economic benefits of €1.3-1.5 billion from an estimated investment of €5-7 billion [7]. As of May 2023, Italy had about ninety RECs with a total installed capacity of 60 MW, with plans to increase this to 5 GW.

In summary, RECs enhance energy security by generating local renewable energy, reduce greenhouse gas emissions, and support economic growth, making them a crucial component in the energy transition and decarbonization process. This should be intended as a clear roadmap for policymakers and stakeholders to maximize the impact of RECs.

Carbon Credits and Legal Instruments for Decarbonization

The landscape of carbon credits has evolved significantly, distinguishing between compliance markets (e.g., EU-ETS) and voluntary carbon markets (VCMs). Unlike compliance markets regulated by stringent legal frameworks, VCMs operate on a voluntary basis, allowing entities to purchase carbon credits to offset their emissions voluntarily. This section delves into the intricacies of voluntary carbon credits, emphasizing their legal and technical implications.

Voluntary carbon credits are financial instruments that represent a reduction or removal of one metric ton of carbon dioxide equivalent (CO_2e) from the atmosphere. These credits are generated through projects that either prevent the emission of greenhouse gases (carbon avoidance) or remove CO_2 from the atmosphere (carbon removal) [8]. Common projects include reforestation, renewable energy installations, and methane capture from landfills.

Legally, the voluntary carbon market lacks the binding regulations that characterize compliance markets. This absence of a universal regulatory framework results in significant variability in the standards and methodologies used to generate and verify carbon credits. Organizations like the Verified Carbon Standard (VCS) and the Gold Standard provide frameworks to ensure the credibility of voluntary carbon credits, yet adherence is not legally enforced. Technically, the creation and validation of voluntary carbon credits involve rigorous processes to ensure that the claimed carbon reductions are real, measurable, permanent, and additional. Projects must undergo validation and verification by independent third parties, who assess the project's adherence to established standards. This includes detailed baseline studies, monitoring plans, and periodic verification audits to confirm ongoing emission reductions.

Despite the challenges, the voluntary carbon market is expanding rapidly, driven by increasing corporate commitments to sustainability and net-zero targets. It is estimated that the market could see investments exceeding $100 billion by 2050 [9]. However, the success of Voluntary Carbon Markets (VCMs) hinges on the ongoing development of robust methodologies and the establishment of clear legal frameworks to enhance transparency and trust. Additionally, the adoption of technologies like blockchain is crucial for improving transparency and accountability [10], which will help to address issues such as greenwashing and double counting [11].

Conclusions

The integration of Renewable Energy Communities (RECs) into Italy's energy framework is pivotal for the country's decarbonization efforts and energy security enhancement. This research emphasizes the necessity for a regulatory framework that not only aligns with European Union directives but also addresses Italy's unique challenges. By fostering collaboration among citizens, small and medium enterprises, and local authorities, RECs can significantly contribute to the energy transition, promoting sustainable development and environmental stewardship.

The potential of RECs is substantial, offering economic, environmental, and social benefits. Economically, RECs can stimulate local economies, generate jobs, and enhance energy independence. Environmentally, they contribute to significant reductions in greenhouse gas emissions by promoting local renewable energy production and consumption. Socially, RECs empower communities, fostering greater public engagement and ownership in energy systems.

While the European Union’s legal framework provides a solid foundation for REC development, there are areas that require further attention to fully realize their potential. Harmonizing definitions and membership criteria across EU member states is essential to reduce legal uncertainties and administrative burdens. Enhancing financial support through grants, low-interest loans, and tax incentives can reduce initial setup costs. Simplifying regulatory procedures and promoting inclusive governance structures can further facilitate the establishment and operation of RECs.

Additionally, leveraging digital technologies such as blockchain can improve transparency and efficiency in REC operations, particularly in managing energy transactions and carbon credits. This technological integration can enhance trust and accountability, mitigating issues like greenwashing and double counting.

In conclusion, RECs represent a transformative approach to achieving Italy's and Europe’s decarbonization goals. By addressing the identified legal, technical, and economic challenges, policymakers and stakeholders can enhance the efficacy and impact of RECs, contributing to broader climate and energy objectives. The synergy between the implementation of local renewable energy production and carbon credit mechanisms exemplifies a virtuous circle for sustainable energy systems and effective climate action at the community level.

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Life cycle assessment of the lithium ion batteries for a more sustainable energy transition

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Abstract
The acceleration of the energy transition, to avoid the most dangerous effects of climate change, has favored the development of energy storage systems, that make renewable energy deployment more effective. This study presents a comparative Life Cycle Assessment (LCA) of Lithium Iron Phosphate (LFP) and Nickel Manganese Cobalt (NMC) battery technologies, focusing on a utility-scale lithium-ion storage system. The LCA evaluates impacts across various life cycle phases, revealing significant differences in resource consumption and environmental burdens. The LFP system demonstrates more efficient resource use and lower carbon emissions. By identifying critical hotspots, such as cobalt sulphate production, and suggesting alternative materials or processes, this study highlights the importance of LCA in guiding decisions for resilient and sustainable energy systems. The findings support a shift towards more reliable and eco-friendly battery chemistries like LFP to enhance a more sustainable energy transition and address resource scarcity challenges.

Keywords: *Life cycle assessment; Lithium ion batteries; Renewable energy; Sustainable development.*

Introduction
The urgent necessity to transition to renewable energy sources, in response to the escalating global greenhouse gas emissions, is generating an increasing demand for critical materials. Despite fossil fuels dominating the world's energy production, renewable sources currently represent about 29% of electricity generation [1]. This share is expected to grow significantly soon, contributing to mitigating climate change. However, the energy transition entails a substantial shift in material usage, as renewable energy systems require more minerals and metals compared to conventional systems [2]. Energy storage systems, essential for managing the intermittency of renewable energies, are experiencing rapid growth.

The energy transition aims to deliver environmental benefits, making life cycle assessment (LCA) a critical tool for comparing different technologies across a wide range of environmental variables.

While pumped hydroelectric storage, with over 90% of global capacity, dominates the energy storage sector, the deployment of battery storage systems primarily drives the sector's growth [3].

As a result, the green and tech transitions are posing challenges to the supply of metals and materials that will be needed in exponentially increasing amounts in the next years.

The supply of these materials, listed by the EU as critical raw materials, like lithium, cobalt, magnesium, manganese, must be evaluated from social, economic, and environmental points of view, which are often interconnected.

In this context, environmental analyses that investigate a product footprint over its whole lifecycle are becoming increasingly relevant and prominent, underscoring the necessity to apply the life cycle assessment methodology to material and energy-intensive sectors.

LCA can compare products or services under different environmental variables and is an integrating instrument for the application of the circular economy and sustainable development principles.

This study conducts a comparative LCA of the two main contenders in the energy storage sector: lithium iron phosphate (LFP) batteries and nickel manganese cobalt (NMC) batteries. Given that most LCA studies focus on batteries in the transport sector [4, 5, 6], or small energy storage applications [7, 8] this work specifically examines grid-scale energy storage systems.The NMC cathode utilizes lithium, nickel, manganese, and cobalt, four critical materials characterized by high costs and significant environmental and social impacts. In contrast, LFP batteries use more common materials such as iron and phosphorus, in addition to lithium, in the cathode. LFP batteries might have better environmental performances than NMC batteries. Still, a quantitative life cycle analysis for impact categories such as carbon emissions, mineral resource use, and fossil resource use, is needed.

Methods

The functional unit is a storage system with a power of 14.7 MW and a capacity of 8.8 MWh. To highlight the impacts of the primary materials supply, a "cradle-to-gate" analysis was performed. Table 1 describes the two energy storage systems layouts.

As with most studies in this field, using primary data has been challenging, so secondary data were chosen after a meticulous bibliographical assessment. For simplicity and the success of the study, the battery system layout and the NMC cell structure have been obtained from "De Lima et al; 2021", while the LFP cell structure from "Zackrisson et al; 2010".

To perform the LCA analysis, Simapro software has been used. The impact assessment method utilized is the CML-IA methodology developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands.

Table 1. Description of the two battery energy storage systems

Parameter	LFP	NMC
Energy capacity (MWh)	8,8	8,8
Power capacity (MW)	14,7	14,7
Total weight (tons)	94,2	76,8
Energy density (Wh/kg)	57,3	71,4
Containers number	5,4	4,4
Cells number	20314	16566

Findings

As shown in the characterization phase results (Fig. 1), which reflect the relative importance of a substance in contributing to a particular impact category, the study's results indicate significant disparities between the two technologies, with the LFP system demonstrating more efficient resource use and lower carbon emissions.

The normalization analysis (Fig. 2), which contextualizes the characterization results and allows the comparability across different impact categories, demonstrates that the minerals and metals resource category is unquestionably the biggest burden for these battery systems.

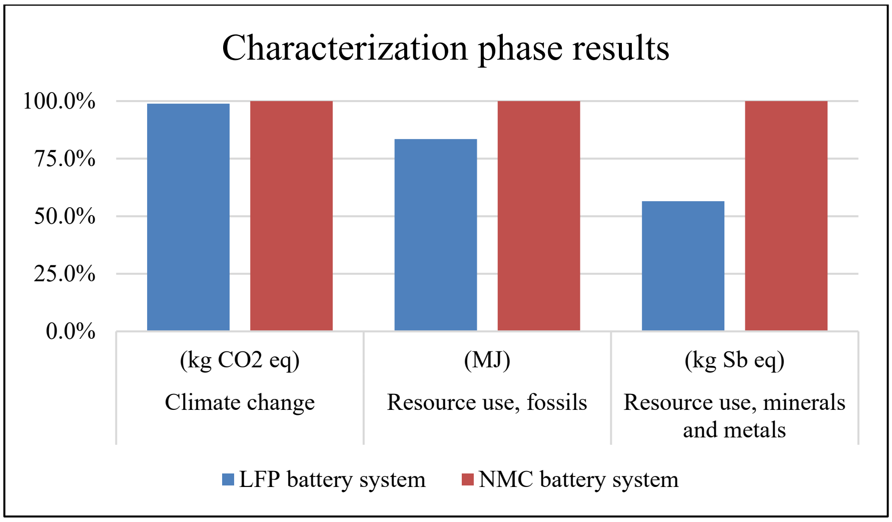

Figure 1. Characterization phase results, bar chart

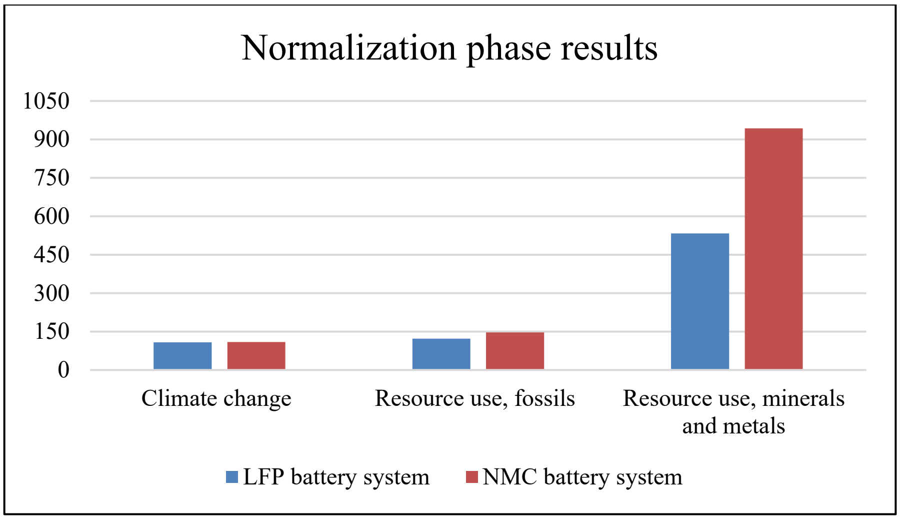

Figure 2. Normalization phase results, bar chart

Lithium-ion batteries utilize critical materials with fragile supply chains and high prices. Furthermore, the most critical material is cobalt, explaining the relevant NMC score in the “minerals and metals resource use” category.

Discussion/Conclusion

This study underscores the importance of the LCA methodology in informing decision-making processes for a transition towards a more resilient and sustainable energy system. LCA studies that consider the use phase and the end-of-life phase are needed to yield a more complete picture of these systems. Furthermore, another point of improvement lies in using direct data from the battery manufacturer (primary data), which are difficult to obtain at present. In conclusion, this study's findings are consistent with current policies and the existing literature, as evidenced by works found in the literature [8, 10]. Notwithstanding these challenges, the study advocates for a shift towards less impacting energy storage technologies, such as LFP batteries, to address the challenges of resource scarcity and long-term environmental sustainability.

The findings highlight the potential environmental benefits of adopting LFP over NMC battery technologies, particularly in decreasing the demand for strategic raw materials.

The deployment of less material-intensive batteries supports the broader goals of the energy transition.

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