Lecture Notes on Multidisciplinary Industrial Engineering
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Paulo Sérgio Brito ·
João Rafael da Costa Sanches Galvão ·
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ICoWEFS 2024 Sustainability Proceedings

Springer

Lecture Notes on Multidisciplinary Industrial Engineering

Series Editor

J. Paulo Davim, *Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal*

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Editors

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Preface

The 4th edition of International Conference on Water Energy Food and Sustainability (ICoWEFS 2024), taken place in Portalegre (May 8-10, 2024) Portugal, aimed to be a major event to foster innovation and exchange knowledge in the water-energy-food nexus, embracing the Sustainable Development Goals (SDGs) of the United Nations, building a better future for all bringing together leading academics, researchers and industrial experts.

Taking into account that the EU has announced several actions for the implementation of the SDGs, such as reducing emissions to achieve climate neutrality by establishing a goal of zero net emissions by 2050, but there will be an interim goal of reducing emissions by 55% by 2030. In addition, the EU required an increase to 45% of renewable sources in the energy mix by 2030, as well as that all new buildings in the EU produce zero emissions from 2030 linked to the plan that in the future, energy consumption should be smaller. The conference will also focus on interconnected areas such as waste and effluent recovery, renewable gases, renewable energies, carbon capture, efficient use of water and sustainable agrifood technologies.

Considering that the EU has announced several actions to implement the SDGs, related to the AGRIFOOD area, such as eradicating hunger, achieving food security, improving nutrition and promoting sustainable agriculture, as well as ensuring sustainable consumption and production patterns, it is It is extremely important to establish these synergies in order to promote networking and collaboration between participants in order to advance knowledge and identify the most viable paths to achieving the objectives.

The conference expects to foster networking and collaboration among participants to advance the knowledge and identify major trends in the above-mentioned fields.

This edition had the submission of more than 70 papers, with authors from several nationalities and with the collaboration of several keynote speakers, who enriched the debate and evolution of the scientific areas, specifically Energy, Sustainability, Water and Food, namely Agrifood. This book publication is focused on the papers within the scope of Sustainability (section 1) and Agrifood (section 2) and is composed of 27 and 11 selected papers that the scientific committee considered relevant to the Sustainability and Agrifood domain.

Welcome to this 4th edition of the ICoWEFS 2023 Conference in Portalegre, Portugal.

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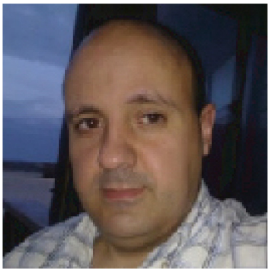

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Keynote Speakers

Ana Luísa Fernando

Researcher at Mechanical Engineering and Resource Sustainability Center (MEtRiCS)

Ana Luisa FERNANDO is an Associate Professor at Universidade Nova de Lisboa, NOVA School of Science and Technology, Portugal. Researcher at MEtRiCS, Mechanical Engineering and Resource Sustainability Center, hosted by Universidade do Minho and Universidade NOVA de Lisboa. Graduated in Applied Chemistry (UNL), in 1990, with a MSc in Food Technology/Quality (1996, UNL) and a PhD in Environmental Sciences (2005, UNL).

She has been working with energy crops for more than 25 years, with special interest on studies related with the Sustainability of energy crops production (use of marginal land; efficient use of water and mineral resources; environmental impact assessment studies to detect options for systems improvement). Parallel to those activities, she has also been working in the field of Food Technology and Safety, by testing natural compounds extracted from plants into biopolymers for food packaging or as additives for food preservation.

Supervision: 9 PhD thesis (concluded), 10 PhD underway, 121 MSc thesis (concluded), 76 Graduation thesis (concluded).

She is also coordinating nationally the H2020 and HORIZON projects GOLD, MIDAS and IASIS. Author and co-author of several publications (h index = 35).

Increasing the sustainable production of biofuels—prospects of cultivating oilseed crops in soils contaminated with heavy metals

Abstract:

The production of oil crops is an auspicious option for the partial substitution of fossil fuels in energy production. Several species can be cultivated for the use of biomass for energy production. Some new oil crops are promising due to their oil yields and quality. In addition to the potential for oil production, some species are capable of tolerating heavy metals from the soil. Thus, the present work aims to investigate the potential of Brassica carinata and Crambe abyssinica in soils contaminated with Zn (450 mg.kg-1, dm), Pb (450 mg.kg-1, dm), Cd (4 mg.kg-1, dm) and Ni (110 mg.kg-1, dm). B. carinata

was the most productive crop (160 g/m2), followed by crambe (130 g/m2). Both oil crops can be considered tolerant to the heavy metals in study (tolerance index higher than 0.75). Yet, the oil content in the seeds was slightly affected by the level of contamination in the soil. Therefore, biodiesel production costs may increase because oil production per land area is affected by the level of contamination. Nevertheless, the production of oil crops in soils contaminated with heavy metals represent an opportunity to provide feedstock for the oleochemical industry, contributing to decarbonize the economy.

Paulo Mira Mourão

Department of Chemistry and Biochemistry, School of Science and Technology, University of Évora

Paulo has a Physics and Chemistry graduation, a master in Physics, and a PhD in Chemistry, Materials and Surface area. In the last years he has consolidated his research in the fields of preparation, characterization, development, and application of porous materials, with the focus on the recovery and valorization of different raw materials and waste, from natural and/or synthetic sources, by its transformation into adsorbents with potential application in the liquid and gas phases, guided by a circular economy perspective. This knowledge and experience provide potential contributions in the areas of water treatment (e.g., drinking and wastewater), space management through the valorization of by-products and waste, of natural and synthetic origin, for use in the preparation of value-added materials (with multiple applications), among others (https://orcid.org/0000-0002-3634-2390).

Activated Carbon and Biochar: Complementary Carbon Materials

Abstract:

Carbon materials are one of the research areas that have attracted significant interest from both academia and industry. This reflects increased knowledge transfer and collaboration between these two sectors, driven by the immense potential of these materials in a wide range of industries, including energy, chemicals, pharmaceuticals, food, healthcare, automotive, railways, aerospace and, in particular, water treatment for both human consumption and wastewater management. Another advantage of carbon materials is that they can be produced from lignocellulosic and synthetic wastes, which are often problematic due to their nature and quantities. Thus, there is also the potential to valorise waste, especially natural and renewable waste, by converting it into high-value materials such as carbon-based adsorbents.

Among carbon-based materials, activated carbon and biochar stand out as versatile materials with complementary structural and chemical properties. Their diverse properties such as porous structure (including pore volume, average pore size, pore size distribution and external surface area) and surface chemistry (specific chemical groups, point of zero charge) facilitate their application in water treatment.

This communication explores the potential of activated carbon and biochar as adsorbents. It presents and discusses the precursors used in their preparation, the production processes and their applications in both liquid and gas phases, supported by concrete examples developed at the University of Évora.

Round Table Event

Exploring agrivoltaics: Opportunities, trade-offs and potential solutions – integrating key aspects through a multiactor perspective discussion

Achieving carbon neutrality relies on renewable energy infrastructures like hydrological dams, photovoltaic arrays, and wind parks, often in agriculturally utilized areas. Despite their crucial role in achieving carbon neutrality while maintaining socioeconomic growth, these infrastructures necessitate careful consideration of their impacts on land systems to achieve net emissions savings. Understanding the intricate interplay between renewable energy infrastructures, ecosystem functions, and political regulatory frameworks is essential for a successful transition to carbon neutrality. This round table discussion focuses on agrivoltaics – integrating perspectives from policy and academia to explore opportunities and trade-offs associated with photovoltaic infrastructures on agriculturally utilized land. By addressing technological, environmental, socio-economic, and political dimensions, the discussion aims to inform strategies for effective carbon emissions mitigation while respecting ecosystems and fostering a sustainable energy transition. It serves as a platform for interdisciplinary dialogue, promoting collaborative solutions for sustainable energy transitions.

Round Table Participants

Luís Fialho – Cátedra das Energias Renováveis, Universidade de Évora

Maximilian Stange – Fraunhofer IWU – Group Leader – Business Models for Sustainability

Filipe Alves – Biovilla, Cooperativa para o Desenvolvimento Sustentável e CHANGE, cEc3, Faculdade de Ciências de Lisboa

Miguel Sequeira – CHANGE, CENSE, Universidade Nova de Lisboa

Fernando Ascensão CHANGE, cE3c, Faculdade de Ciências de Lisboa

Representative from Public Administration

Round Table Moderator

Susana Filipe, CHANGE

Round Table Organizers

Dominik Noll
MED, CHANGE, Portugal

Flávio Oliveira
cE3c, CHANGE, Portugal

Susana Filipe
MED, CHANGE, Portugal

CHANGE
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Conference Awards

The ReadyToPub Awards will be given to the best student oral communications and the best student posters (general and female participants). The main aim of the ReadyToPub Awards is to motivate and encourage young researchers to prepare their data and, with the help of ReadyToPub, attempt to publish papers in international journals with a high impact factor.

The evaluation of the communications will be based on five criteria. The awards consist of a credit worth €250 (best oral communications) and €150 (best posters) for use in services provided by ReadyToPub. The winners will be announced at the conference closing ceremony.

Best student oral presentation:

Author: Eduardo Costa Camilo

Title of the presentation: Future-proof a mediterranean soup

Best female student oral presentation:

Author: Santa Margarida Santos

Title of the presentation: Characterization of refuse derived fuel pellets and feasibility assessment of their application in CO2 gasification

Best Poster and Best Female Student Poster:

Author: Sara Hassan

Title of the poster: The short-term effect of prescribed burning on aboveground biomass, and soil properties

Award Sponsor

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The conference co-chairs and organising committee wish to acknowledge the support and sponsorship given in the organisation of the ICOWEFS 2024 – International Conference on Water Energy Food and Sustainability, held at the Polytechnic Institute of Portalegre, Portugal.

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Contents

Sustainability

The following section contains papers related to “Sustainability”.

Development and Characterization of Biodegradable Films Based on Pectin and Galega Kale By-Products

Leopoldina Carlos[1,2], Nelson Pereira[1,2], Margarida Moldão Martins[1], Vítor D. Alves[1(✉)], and Elsa M. Gonçalves[2,3(✉)]

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Abstract. The by-products of Galega kale, composed mainly of stems and leaves, represent an interesting source of bioactive compounds with various functionalities. The aim of this work was to develop and characterise functional pectin-based films using Galega kale powder as fillers, obtained from by-products of vegetable processing. The fresh by-products were blanched (100 °C/ 30 s), dried (80 °C/ 8 h) and milled, followed by their characterization in terms of total phenolic content and antioxidant activity. Pectin films were produced using the casting method, and characterized in terms of their bioactive, optical, mechanical and hygroscopic properties. Adding the by-products powder into the pectin matrix (0, 5, 10 and 20%) makes the films opaquer and with a more heterogeneous and yellowish colour. The incorporation of Galega kale powder at 20% significantly increased the films tensile stress at break (89%) and Young's modulus (230%), compared to that of control film. However, water vapour permeability decreased around 45%. The same film showed higher total phenolic content (0.96 ± 0.08 mg GAE.g^{-1} dw), higher antioxidant potential with DPPH (2.94 ± 0.61 µmol TE.g^{-1} dw), ABTS (2.12 ± 0.24 µmol TE.g^{-1} dw) and FRAP methods (6.04 ± 1.47 µmol TE.g^{-1} dw). Thus, Galega kale by-products could be valued with the production of low-cost and environmentally friendly biodegradable films, with potential to be used in active packages with antioxidant activity.

Keywords: Galega kale by-products · Powders · Biodegradable films · Pectin films · Antioxidant activity · Active packaging

1 Introduction

Galega kale (Brassica oleracea L. var. Acephala cv. Galega) is a cruciferous vegetable and one of the most important kale varieties with an important position in the Mediterranean´s culinary and diet [1]. In Portugal, shredded Galega kale is usually processed and

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marketed as a fresh-cut product, offering consumers a convenient and appealing product rich in beneficial of several phytonutrients, such as phenolic compounds, substances with antioxidant and anti-inflammatory properties [2, 3]. In addition to the mentioned nutrients, the Brassica vegetable family has other phytonutrients known as glucosinolates (GLs), which are sulphur-containing chemicals. Glucosinolates and their derived products have been recognised by their benefits to human nutrition, plant defence, and as potent antimicrobial agents [4, 5]. However, these unstable compounds degrade biologically active indoles and isothiocyanates under the influence of the myrosinase enzyme in plant tissues.

The increasing consumption and production of fresh-cut Galega kale products have led to an increase in by-products and secondary outcomes (e.g. petioles, parts of leaves) that are often discarded or wasted during the manufacturing stages of their processing. The usual ways of disposing of these materials are animal feed and com-posting. However, difficulty in managing these materials due to their perishability and the low economic return leads to the search for new alternatives. Recent research indicates that similar vegetable by-products are a rich source of nutrients, bioactive compounds, and biopolymers such as dietary fibre or polysaccharides [6, 7]. This fact gives rise to a growing interest in the partial or total recovery of the by-products generated, creating a potential source of materials with different applicability in different sectors and with other functionalities [8], generating a circular economy that allows for better management of these materials.

One way of valorisation is the use of agro-industrial by-products as renewable sources of materials for the development of innovative biodegradable films [9–15], with potential to reduce the serious environmental problems caused by the non-biodegradability of synthetic polymers derived from fossil fuels, which constitute the traditional plastic food packaging [16, 17].

Among the polysaccharides often used to develop biodegradable films are starch, alginate, pectin, cellulose and carrageenan. These biopolymer materials can decompose in the environment by living organisms under appropriate humidity, temperature, and oxygen conditions, without the residue of toxic or harmful substances to the environment [18].

Pectin films used to preserve food have been studied [19–21] and the characteristics of these films depend on different factors such as the source of pectin [22–25], the methoxyl content [19, 26], and the type of plasticizer [27]. However, in general, pectin films face some challenges related to their mechanical properties and their permeability to water vapour due to their hydrophilic characteristics, limiting their application [28]. Therefore, to achieve better performances in the development of biodegraded films, a wide range of by-products or natural compounds could be added to improve the characteristics of the packaging material, such as antioxidant and antimicrobial characteristics [6, 9, 10, 29] or functionality [30, 31].

With the objective of valorisation of Galega kale by-products by producing active pectin films, this study performed a physical-chemical characterization of the Galega kale by-products and of their dried powders, followed by the formulation and characterizion of pectin films with incorporation of Galega kale powders.

2 Materials and Methods

2.1 Materials

Galega kale by-products (30 kg) were composed of leaf ends and stems, and were provided by Campotec S.A. located in Torres Vedras (Portugal). The vegetable material was stored in at refrigerated chamber at 4 °C until used.

The pectin used in preparation of films was low methoxyl pectin (Cargill France SAS) and glycerol was used as plasticizer. Folin-Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), 2,4,6-Tri(2-pyridyl)-s-triazine (TPTZ), gallic acid (GA) and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were acquired from Sigma Aldrich Chemical Co. (St. Louis, MO, USA).

2.2 Preparation of Galega Kale Powders

Galega kale fresh by-products (FS; ≈10 kg) were divided into two subsamples. One of them was blanched to inactivate myrosinase enzyme, in a stainless steel vessel at 100 °C for 30 s, the proportion of water to the raw material being 3:1 by weight. After blanching, the vegetable material (BS) was cooled in a water bath containing ice for 15 s, and afterwards the excess water was removed with absorbent paper [2, 32].

Further, the FS and BS materials were dehydrated (FS_D and BS_D, respectively) at 80 °C for 8 h (until constant weight—optimisation previously performed, data not shown) in a circulating air oven (Heraeus, electronic, Spain), followed by grounding in a mill (Fritsch Pulverisette 14, Germany) to obtain the respective powders with a particle size of 0.12 mm. The powders obtained (FS_P and BS_P) were stored in a desiccator at room temperature (~25 °C) until used. All these procedures were repeated three times to obtain three independent batches of each sample (FS, FS_D, BS_D, FS_P and BS_P). All the samples were analysed as described in 2.4.

2.3 Preparation of Films

Pectin films were prepared according to the casting method and based on the methods reported by Meerasri & Sothornvit (2020) [33] and Khodaei et al. (2020) [34].

The filmogenic solution was prepared through the dissolution of pectin in water, with a concentration of 2% (w/v). The filmogenic solution was stirred (Arex, Velp Scientifica, Italy) at 650 rpm until the complete dissolution of pectin, after which glycerol was added at a content of 25% ($w_{\mathrm{glicerol}}/w_{\mathrm{pectin}}$), and the mixture was stirred at room temperature. The resulting filmogenic solutions (Control film) were poured into Petri dishes (0.7 g/cm^2) and dried in an oven (Binder, Germany) at 40 °C for 20 h. After drying, the films were peeled off from the casting surface and kept at 25 °C for further analysis.

The pectin films incorporating blanched Galega kale by-products powder (BS_P) were prepared by adding the fine powder in different proportions (5, 10 and 20%, mass of BS_P per mass of pectin) to the filmogenic solution under magnetic stirring for 5 min. After this period, the casting and drying methodology described above was applied. All films (0%- Control film; 5, 10 and 20% BS_P) were characterized as listed below.

2.4 Physical-Chemical and Bioactive Evaluation of Fresh By-Products, Powders and Films

Moisture content (MC) and water activity (a_w). The MC of the fresh by-products (FS) and powders (FS_P and BS_ P) was determined using NP-875 [35] and 2 g of material. The MC determination of films followed the same methodology using film samples with 2 cm x 2 cm. The a_w of the fresh by-products and powders were determined using a digital hygrometer (Hygrolab 2, Rotronic AG., Bassersdorf, Switzerland).

Bioactive evaluation. Fresh by-products (FS) and powders (FS_P and BS_P) extracts were prepared using methanol as solvent, with a biomass:solvent ratio of 1:8 (w:v). The film extracts were prepared using a mass of film:methanol proportion of 3:10 (w:v). Each mixture was homogenised (Ultra-Turrax T 25 basic, IKA—Werke, Germany) at 19 000 rpm for 2 minutes. Then, the mixtures were stored in the dark at 4 °C for 24 h. After that period, each mixture was centrifuged at 7000 rpm for 20 min at 4 °C (Sorvall RC5C, rotor SS34, Sorvall instruments). The mixtures of film samples with methanol (0 %, 5 %, 10 % and 20 %) were filtrated using a syringe filter. All supernatants were stored in the dark at 4 °C until the analysis time. The extracts were performed in independent triplicates for each sample of by-products, powders and films.

Total phenolic compounds content. The total phenolic compounds content (TPC) was determined by the Folin- Ciocalteau method, as proposed by Alegria et al. (2021) [36]. The results were expressed as mg gallic acid equivalents per g dry weight (mg GAE.g^{-1} dw), using a standard curve of gallic acid as a reference.

DPPH radical scavenging capacity. The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging capacity was determined using the method described by Brand-Williams et al. (1995) [37] with some modifications. The DPPH solution was prepared with methanol, and it was diluted until reaching an absorbance of 1.1 ± 0.02 at 517 nm. For the radical scavenging evaluation, an aliquot of 150 μl of extract was added to 2850 μl of DPPH solution. Then, the samples were vortexed and the reaction occurred for 2 h in the dark at room temperature. After that period, the absorbance was measured at 517 nm against methanol. The results were expressed as µmol Trolox Equivalents per g dry weight (µmol TE.g-1 dw), based on a standard curve of Trolox.

ABTS free radical capture. The ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) method was performed according to Rufino et al. (2007) [38]. An ABTS$^+$ solution was produced by reaction of 5 mL of ABTS stock solution and 88 μL of a 140 mM potassium persulfate ($K_2S_2O_8$) solution to give a final concentration of 2.45 mM. A volume of 30 μL of extract was mixed with 3000 μL of ABTS$^+$ solution, followed by incubation for 6 min in the dark. Then, the absorbance was measured at a wavelength of 734 nm. The antioxidant activity was expressed in µmol Trolox Equivalents per g dry weight (μmol TE.g^{-1} dw), based on a standard curve of Trolox.

Ferric reducing antioxidant power. The antioxidant activity by ferric reducing antioxidant power (FRAP method), was measured as described by Benzie & Strain (1996) [39] with some modifications. The FRAP reagent solution was obtained by mixing 50 ml of 0.3 M acetate buffer solution with a pH of 3.6, 5 ml of 10 mM TPTZ solution, and 5 ml of 20 mM ferric chloride solution. The mixture was placed in a water bath at 37 °C for 20 minutes. Subsequently, the assay was carried out with 3 ml of FRAP reagent and 0.1 ml of extract, followed by shaking and incubation in a water bath at 37 °C for

20 minutes. Afterwards the absorbance was measured at 595 nm, using a JASCO V-530 UV/VIS- Spectrophotometer (Jasco International, Tokyo, Japan). A standard curve was prepared using different concentrations of trolox. The results were expressed as μmol Trolox Equivalents per g dry weight (μmol TE.g-1 dw).

Water vapor permeability (WVP) and water vapour adsorption isotherms of films. The water vapor permeability was measured using a gravimetric method according to the methodology used by Alves et al. (2011) [40]. The film samples consisted of circles of 6 cm in diameter and were sealed at the top of petri dishes with a diameter of 7 cm, which contained 9 ml of a saturated solution of NaCl ($a_w = 0.753$). The petri dishes are then placed in an airtight desiccator containing a saturated salt solution of $MgCl_2$ ($a_w = 0.369$) and weighed every 1.5 hours to measure the water flow through the film.

The WVP (mol.m/(m^2.s.Pa)) was calculated using the following Eq. (1):

$$\mathrm{WVP} = \frac{N_{wf} \times \delta}{\Delta P} \tag{1}$$

In which N_{wf} represents the molar flux of water vapour (mol/ (m^2.s)), δ represents the film thickness (m), and ΔP represents the water vapour pressure difference between the two sides of the film (Pa).

The water vapour adsorption isotherms were measured gravimetrically [40]. Three samples of each film (0, 5, 10 and 20% BS_P) were cut in squares of 2 x 2 cm and placed in the different desiccators, each one with a distinct saturated solution: LiCl, CH_3COOK, $CaCl_2$, K_2CO_3, $NaNO_2$, NaCl, KCl, $BaCl_2$, with water activity at ~ 25 °C of 0.115, 0.306, 0.432, 0.436, 0.623, 0.729, 0.819, 0.872, respectively. After three weeks, the films were weighed (m_1), dried for 24 h in a drying oven at 70 °C and stored in a desiccator with silica gel. After one week, the films were weighed again (m_2). Equation (2) was used to calculate the water vapour adsorbed per dry mass of each sample (X; %):

$$X(\%) = \frac{m_1 - m_2}{m_2} \times 100 \tag{2}$$

The water adsorption isotherms where obtained by representing X values as a function of the water activity.

Film thickness and mechanical properties. The film thickness was measured using a digital micrometer (Mitutoyo, Japan), taking at least five measurements at different points of each film.

The mechanical properties were analysed by axial stress tests using a texturometer (TA-XT plus, Stable Micro Systems, England) to determine three parameters: tensile stress at break (TS), elongation at break (E) and Young's modulus (YM). Five rectangular strips of 5 × 1 cm were cut for each film sample and conditioned at 25 °C and 52% humidity for 48 h before testing. The strips were attached to tensile grips with an initial distance of 3 cm, and deformed until the breaking point at a crosshead speed of 1.0 mm/s.

Optical properties of films. Colour measurements were performed using a colorimeter (Minolta CR-300, Osaka, Japan) previously calibrated with a standard with tile (EU certified; $L^* = 84.67$, $A^* = -0.55$, and $B^* = 0.68$), which recorded the spectrum of reflected light to determine the parameters L^*, a^*, and B^*. From CIELab colour space it can be obtained CIELCH colour space, that besides L^* defines the colour by C^* (colour saturation, which goes from −60 to +60) and $h°$ (hue angle that represents colour tone). The saturation (C^*) and hue angle ($h°$) of the colour were calculated using the following Eqs. (3–6):

$$C^* = \left(a^{*2} + b^{*2}\right)^{\frac{1}{2}} \tag{3}$$

$$h^\circ = \arctan\left(\frac{b^*}{a^*}\right) \times \frac{180}{\pi}, \text{ for } a* > 0 \text{ and } b^* > 0 \tag{4}$$

$$h^\circ = \left(\arctan\left(\frac{b^*}{a^*}\right) \times \frac{180}{\pi}\right) + 180, \text{ for } a^* < 0 \tag{5}$$

$$h^\circ = \left(\arctan\left(\frac{b^*}{a^*}\right) \times \frac{180}{\pi}\right) + 360, \text{ for } a^* > 0 \; e \; b^* < 0 \tag{6}$$

The colour parameters were measured using four different coloured cardboards (white, yellow, green and red). The cardboards colour was determined when uncovered and covered by the film samples. The difference between the colour of cardboards covered by the films and the cardboards alone (ΔE), was obtained by the Eq. (7):

$$\Delta E = \left[(\Delta L)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2\right]^{1/2} \tag{7}$$

Statistical analysis. The results were expressed as the mean and standard deviation of at least three replicates. The results were subjected to analysis of variance (ANOVA) using the Statistic software 12.0 (2013). The correlation between TPC and antioxidant activity (DPPH, ABTS, FRAP) is presented by pearson correlation coefficient. Tukey's HSD test was used to assess the existence of significant differences ($P < 0.05$) between samples.

3 Results

3.1 By-Product and Powders Evaluation

Table 1 provides the average moisture content (MC), water activity (a_w), total phenolic content (TPC) and antioxidant activity results of the fresh Galega kale by-product (FS) and powders (FS_P and BS_P).

As expected, the MC and a_w of by-products were reduced after drying and milling. The fresh by-product sample has an MC of 90.47%, similar to vegetables of Brassica spp. [41–43]. The MC of FS_P and BS_P were reduced by about 93% and 94% relative to fresh by-products, respectively. The a_w of the fresh by-product has a high value (0.95) that contributes to the perishability of Galega kale. The values obtained in the powder samples are less than 0.5, which makes it possible to estate that these powders present a higher microbiological stability [44] with consequent longer storage shelf-life.

The fresh Galega kale by-products present a slightly lower TPC value (4.65 mg GAE.g^{-1} dw) compared to that reported by Armesto et al. (2015) [45] (7.6 mg GAE.g^{-1} dw) and Martínez et al. (2010) [41] (5.2 mg GAE.g^{-1} dw) in edible parts of Galega kale

Table 1. Fresh by-product (FS) and powders (FS_P and BS_P) characterisation: moisture content (MC), water activity (a_w), total phenolic content (TPC) and antioxidants activity by DPPH, ABTS and FRAP methods. Different letters (a, b, c) in the same column are significantly different as determined by Tukey's test ($p < 0.05$).

Sample	MC (%)	a_w	TPC (mg GAE.g^{-1} dw)	DPPH (μmol TE.g^{-1} dw)	ABTS (μmol TE.g^{-1} dw)	FRAP (μmol TE.g^{-1} dw)
FS	90.47a ± 0.22	$0.95^a \pm 0.00$	$4.65^a \pm 0.13$	$11.66^a \pm 1.13$	$10.45^a \pm 2.55$	$26.49^a \pm 2.30$
FS_P	6.38b ± 0.17	0.31b ± 0.07	$2.67^b \pm 0.06$	$5.75^b \pm 0.10$	$3.71^b \pm 0.16$	$17.31^b \pm 0.44$
BS_P	$5.79^b \pm 0.51$	$0.26^b \pm 0.03$	$2.41^c \pm 0.02$	$5.63^b \pm 0.16$	$3.73^b \pm 0.37$	$18.46^b \pm 2.14$

obtained under similar experimental conditions. Anyway, these by-products are still a rich source of these compounds.

TPC declined significantly with drying, as the value for Galega kale by-product powders was 2.67 and 2.41 mg GAE.g^{-1} dw for FS_P and BS_P, respectively. Heat treatments, e.g. blanching and drying, are one of the oldest procedures for food processing and preservation. However, they can change the food products profile on a physical, biological, and chemical level. These immediate dietary changes are linked to the temperature sensitivity of phytochemicals and the ensuing notable losses in vitamins, antioxidants, and other bioactive substances [1, 46]. This fact is the leading cause of the decline in TPC seen in the current study.

To determine the changes in antioxidant activity in fresh Galega by-products (FS), after blanching and after drying, three common assays (DPPH, ABTS and FRAP) were used in this research (Table 1). The value of antioxidant activity of FS by DPPH, ABTS and FRAP methods was found to be 11.66 μmol TE.g^{-1} dw, 10.4 μmol TE.g^{-1} dw and 26.49 μmol TE.g^{-1} dw. It was observed a statistically significant decrease of the three antioxidant activities values ($p < 0.05$), by approximately 51, 64 and 35%, respectively, in the respective dried samples, confirming the destructive effect of drying. The blanching operation did not show a significant effect.

Fresh and powder samples showed a strong and positive relationship between TPC and the antioxidant activities measured in DPPH, ABTS and FRAP assays, with Pearson correlation coefficients (r) ranging between 0.903–0.984 (Table 2). Such finding suggests that phenolic compounds of by-product Galega kale has a great influence on antioxidant capacity.

Table 2. Pearson Correlation between the studied total phenolic content (TPC) and antioxidant capacity for extracts of fresh and powders samples. Values in bold are significant at $p < 0.05$.

	TPC	DPPH	ABTS	FRAP
TPC	1	0.984	0.903	0.905
DPPH		1	0.868	0.873
ABTS			1	0.934
FRAP				1

The correlation between DPPH and ABTS methods was significant ($r = 0.868$, $p < 0.05$); however lower compared with other correlations. The FRAP method was strongly correlated with ABTS ($r = 0.934$, $p < 0.05$) and DPPH ($r = 0.873$, $p < 0.05$) methods. Although exist a high relationship between assays, the differences in results can be explained by the presence of compounds that are poor DPPH and ABTS radical scavengers [47].

3.2 Films Characterisation

Visual appearance and colour. Adding the by-product powder to pectin films gave the films a yellowish colour (Fig. 1). The cardboards colour parameters measured when covered by the film samples are presented in Table 3.

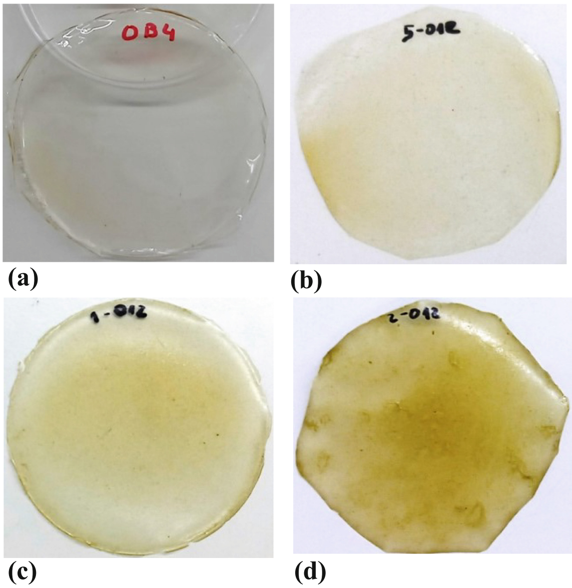

Fig. 1. Visual appearance of the four films: (a) Control film 0% of powder; (b) film with 5% of powder; (c) film with 10% of powder, and (d) film with 20% of powder.

The colour saturation (C*) was lower when the films were overlaid on white cardboard, and the values were increased by adding Galega kale by-product powder. However, for the remaining cardboards, there was a decrease in this parameter when there was an increase in the concentration of by-product powder.

In terms of colour hue (h°), the results obtained for all cardboards present significant differences ($p < 0.05$), the exception being for white cardboard covered with control, 5 and 10% powder. The films change the colour hue in different ways. It's observed that adding powder to films decreases the colour hue of all carboards, except for red cardboard, where there's an increase in this parameter.

All films seem to significantly change the colour of cardboards. The colour differences were higher as the Galega kale by-product powder concentration increased, and the results obtained for the white and green cardboards were significantly different ($p < 0.05$). Though, ΔE values obtained for the red cardboard were identical between the control, 5% and 10% films. The colour difference was also identical for the yellow cardboard between control and 5% films.

Mechanical properties. Table 4 shows the results of thickness and physical-mechanical properties of the control film and films with 5, 10 and 20% powder.

Table 3. Colour parameters of the control film and films with 5, 10 and 20% Galega kale powder. Colour saturation (C^*), colour hue ($h°$), colour differences (ΔE). Different letters (a, b, c, d) in the same column indicate significantly different values as determined by Tukey's test ($p < 0.05$).

Colour	Film	C^*	$h°$	ΔE
White	Control	$6.63^{a} \pm 0.88$	$97.28^{a} \pm 0.37$	$3.32^{a} \pm 1.13$
	5%	$11.19^{b} \pm 1.23$	$97.09^{a} \pm 0.22$	$8.18^{b} \pm 1.38$
	10%	$14.84^{c} \pm 1.22$	$96.87^{a} \pm 0.40$	$12.17^{c} \pm 1.35$
	20%	$21.88^{d} \pm 2.04$	$95.15^{b} \pm 0.49$	$20.39^{d} \pm 2.38$
Yellow	Control	$68.22^{a} \pm 1.22$	$94.31^{a} \pm 0.19$	$10.02^{a} \pm 1.07$
	5%	$68.44^{a} \pm 0.49$	$93.39^{b} \pm 0.25$	$10.36^{a} \pm 0.35$
	10%	$67.94^{a} \pm 0.47$	$92.74^{c} \pm 0.35$	$11.54^{b} \pm 0.27$
	20%	$65.57^{b} \pm 0.38$	$91.03^{d} \pm 0.56$	$16.37^{c} \pm 0.93$
Green	Control	$49.36^{a} \pm 0.42$	$134.21^{a} \pm 0.36$	$10.58^{a} \pm 0.42$
	5%	$48.71^{b} \pm 0.25$	$132.31^{b} \pm 0.41$	$11.34^{b} \pm 0.27$
	10%	$47.94^{c} \pm 0.23$	$130.81^{c} \pm 0.44$	$12.51^{c} \pm 0.14$
	20%	$44.90^{d} \pm 0.30$	$127.10^{d} \pm 0.75$	$16.91^{d} \pm 0.53$
Red	Control	$51.80^{ab} \pm 0.45$	$31.92^{a} \pm 0.39$	$12.50^{a} \pm 0.59$
	5%	$51.84^{b} \pm 0.27$	$33.73^{b} \pm 0.41$	$12.08^{a} \pm 0.34$
	10%	$51.24^{a} \pm 0.34$	$35.60^{c} \pm 0.47$	$12.58^{a} \pm 0.35$
	20%	$48.56^{c} \pm 0.71$	$39.25^{d} \pm 1.09$	$15.82^{b} \pm 0.47$

Incorporating Galega kale powder (5, 10 and 20%) in the formulation of pectin films increased their thickness around 37, 39 and 41%, respectively, comparing to that of control film. However, among the films containing powder the thickness values are statistically identical ($p > 0.05$). The powder of Galega kale by-products added is composed of both soluble and insoluble fibres, which cannot completely solubilize in the film-forming solution. Thus, insoluble particles are present in the films.

In what concerns mechanical properties, increasing powder content led to an increase in the tensile strength at break. This increase may be attributed to the dispersion of the particles throughout the matrix, resulting in good tension transfer and consequently increasing the cohesion [48]. Andrade et al. (2016) [9] presented a similar behaviour for tensile strength at break in films with increasing powder (from fruit and vegetable residues) incorporation. The control film presented the higher elongation at break value. This parameter tended to decrease with Galega kale by-product powder incorporation. This fact may be due to the significant interaction of the particles with the pectin molecules when in greater quantity in the polymeric matrix, limiting the displacement of the polymeric chains during the axial tension test.

In the work of Khodaei et al. (2020) [34] and Younis et al. (2020) [49], pectin films presented a tensile strength at break of 8.4 MPa and 9.35 MPa, respectively, these values being similar to those obtained for the control film in the present work (7.85 MPa).

Table 4. Physical-mechanical properties of the control film and films with 5, 10 and 20% Galega kale powder. Moisture content (MC), Water vapor permeability (WVP), tensile stress at break (TS), elongation at break (*E*) and Young's modulus (YM). Different letters (a, b, c) in the same column indicate significant differences as determined by Tukey's test ($p < 0.05$).

Film	Thickness (mm)	MC (%)	WVP ($\times 10^{-11}$ mol.m/m^2.s.Pa)	TS (MPa)	*E* (%)	YM (MPa)
Control	0.070a ± 0.02	$40.57^{a} \pm 1.89$	$2.29^{a} \pm 0.21$	$7.85^{a} \pm 2.78$	$32.7^{a} \pm 4.4$	$19.96^{a} \pm 6.41$
5%	0.096b ± 0.01	$36.57^{a} \pm 4.37$	$2.16^{a} \pm 0.34$	$12.32^{ab} \pm 1.66$	$26.0^{ab} \pm 5.4$	$36.83^{b} \pm 8.90$
10%	0.097b ± 0.01	$42.75^{a} \pm 4.23$	$2.29^{a} \pm 0.43$	$13.19^{b} \pm 0.82$	$32.4^{a} \pm 3.8$	$25.88^{ab} \pm 3.33$
20%	0.099b ± 0.02	$35.93^{a} \pm 1.55$	$1.55^{a} \pm 0.21$	$14.83^{b} \pm 3.30$	$17.9^{b} \pm 5.8$	$65.95^{c} \pm 9.17$

However, in the same studies, the elongation at break values show differences when compared to that obtained for control film in the present work. Khodaei et al. (2020) [34] obtained a value of 16% and Younis et al. (2020) [49] indicated an elongation at break value of 63%. These differences can be explained to different film formulations, such as the use of high methoxyl pectin and different amounts of plasticiser.

In addition, Young's modulus values increased with increasing powder content. These results reflect the chemical and structural compatibilities between the pectin matrix and powder particles [48]. The value of Young's modulus for the 20% film (65.95 MPa) was about three times higher than the value of the control film. Thus, the 20% film represents the film with the highest resistance to deformation in the elastic zone. The control is the least resistant since it has the lowest Young's modulus value (19.96 MPa). This result is among those obtained by Younis et al. (2020) [49] and Meerasri & Sothornvit (2020) [33], where for pectin films, they presented Young's modulus of 13.10 MPa and 23.87 MPa, respectively.

Water vapour permeability. It is observed that the incorporation of powder particles in the pectin polymeric matrix doesn't significantly affect the water vapour permeability (WVP) value ($p > 0.05$) (Table 4). However, there is a tendency for a lower value for the film of 20% of by-product powder. The difference between the 20% powder film and the other films under study can be explained by the fact that a more significant amount of particles present in the pectin matrix allows for a reduction in the intermolecular space and water diffusion coefficient, consequently resulting in a reduction in the transfer of water vapour.

The results obtained for the four film formulations (control, 5 10 and 20%) are superior when compared to other studies. Meerasri & Sothornvit (2020) [33] showed a WVP value of 6.4×10^{-12} mol/m.s.Pa for pectin films; Martelli et al. (2013) [50] obtained a value of 1.38×10^{-11} mol/m.s.Pa for films with 5% incorporation of banana residues and Andrade et al. (2016) [9] showed a WVP value of 1.18×10^{-11} mol/m.s.Pa for films with 10% fruit and vegetable residue powder. The differences can be explained by experimental conditions (temperature, relative humidity), the amount used in the formulation of the film, and the different characteristics of the material incorporated in the matrix of the films.

Water vapour adsorption capacity. The water vapour adsorption capacity of the different films is represented in Fig. 2. The results demonstrate that it is possible to validate the hydrophilic nature of the films, since the amount of water vapour adsorbed increases with the increase in water activity provided by the different saline solutions. All the films incorporating different concentrations of Galega kale by-product powder (5, 10 e 20%) present a similar behaviour, with a water vapour adsorption capacity between 4.9% and 94.2%. The control film has the highest water vapor adsorption capacity compared to the other films since it doesn't have the by-product particles in its matrix.

Bioactive properties of films. Table 5 presents the results of the total phenolic content and antioxidant activity of the films.

The control film presented a total phenolic content value of 0.22 mg GAE.g^{-1} dw. This value is lower when compared with the study of Meerasri & Sothornvit (2020) [33], who showed for pectin films a total phenolic content of 1.2 mg GAE.g^{-1} dw. This difference may be due to the different film formulation, since the referred authors used

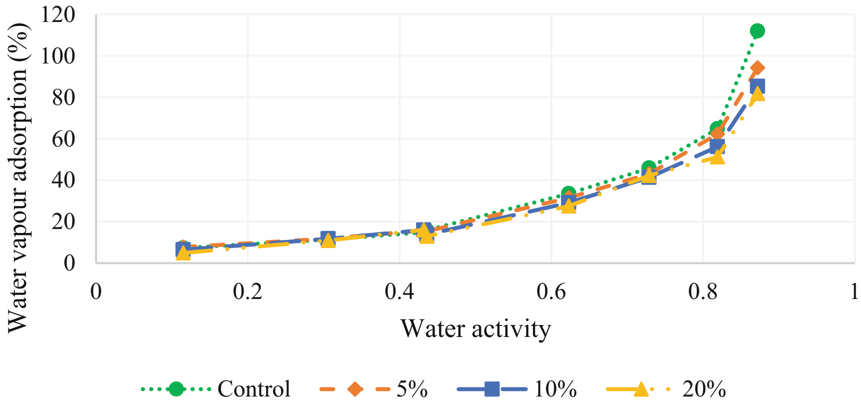

Fig. 2. Water vapour adsorption isotherms for control film and films with 5, 10 and 20% of galega kale powder.

Table 5. Total phenolic content and antioxidant activity of the control film and films with 5, 10 and 20% Galega kale powder. Total phenolic content (TPC); antioxidant activity by DPPH, ABTS and FRAP methods. Different letters (a, b, c) in the same column are significantly different, as determined by Tukey's test ($p < 0.05$).

Film	TPC (mg GAE.g^{-1} dw)	DPPH (μmol TE.g^{-1} dw)	ABTS (μmol TE.g^{-1} dw)	FRAP (μmol TE.g^{-1} dw)
Control	$0.22^{a} \pm 0.03$	0.22a ± 0.13	$0.97^{a} \pm 0.06$	$0.93^{a} \pm 0.04$
5%	$0.46^{b} \pm 0.03$	1.06ab ± 0.12	$1.26^{a} \pm 0.04$	$2.52^{ab} \pm 0.29$
10%	$0.75^{c} \pm 0.10$	1.93b ± 0.35	$1.76^{b} \pm 0.18$	$3.51^{b} \pm 0.55$
20%	$0.96^{d} \pm 0.08$	2.94c ± 0.61	$2.12^{b} \pm 0.24$	$6.04^{c} \pm 1.47$

high methoxyl pectin and a lower amount of glycerol, concerning the mass of pectin. As could be expected, the addition of Galega kale by-product powder increased significantly ($p < 0.05$) the total phenolic content in the films. The film filled with 20% of by-product powder presented the highest total phenolic content (0.96 mg GAE.g^{-1} dw), five times higher than the control film.

When kale by-product powder is added to the pectin polymer matrix there is an increase ($p < 0.05$) in the antioxidant capacity of the films, obtained by the three assays (DPPH, ABTS and FRAP). Crizel et al. (2018a) [51] also observed increased antioxidant activity (DPPH and FRAP) in chitosan films incorporated with olive pomace powder.

The control film showed the lowest antioxidant capacity value by the DPPH assay (0.22 μmol TE.g^{-1} dw). This value is lower than that found by Meerasri & Sothornvit (2020) [33] (1.38 μmol TE.g^{-1} dw) for high methoxy pectin films. The addition of 10% and 20% powder significantly increased ($p < 0.05$) the DPPH radical-scavenging activity, around 8 and 12 times, respectively. The FRAP ferric-reducing antioxidant activity of filled films with 20% was the highest value (6.04 μmol TE.g^{-1} dw) and was six times higher than the control film. The results obtained by ABTS assay presented minor changes between the film samples.

The TPC was strongly correlated with antioxidant activity (Table 6), DPPH ($r = 0.981$, $p < 0.05$), ABTS ($r = 0.986$, $p < 0.05$) and FRAP ($r = 0.952$, $p < 0.05$).

Table 6. Pearson Correlation between the studied total phenolic content and antioxidant capacity for extracts of the control film and films added with powder. Values in bold are significant at $p < 0{,}05$.

	TPC	DPPH	ABTS	FRAP
TPC	1	0.981	0.986	0.952
DPPH		1	0.992	0.983
ABTS			1	0.962
FRAP				1

This fact was consistent with the contribution of the phenolic compounds present in vegetable material for antioxidant capacity. The similarity in the antioxidant activity results can be explained by high correlations among the DPPH, ABTS and FRAP assays, with Pearson correlation coefficients ranging between 0.962–0.992.

4 Conclusions

Biodegradable films pectin filled with Galega kale by-products in the form of powder have been successfully developed. The incorporation of Galega kale by-product powder improves the films strength and the barrier to water vapour. However, it imparts a yellowish colour, compromising the films transparency. Though, when including by-product powder in the polymeric matrix, the films show excellent antioxidant properties. The highest antioxidant activity by DPPH and FRAP methods was 2.5 and 6 μmol TE. g^{-1} dw, respectively, for films incorporated with 20% of powder. The results suggest that pectin films incorporated with 20% of Galega kale by-product powder have a significant potential to be used in active packages for food products with low water content. Still, further studies are needed (e.g. antimicrobial properties and shelf-life studies), to optimise films properties. This approach also increases the agro-industrial potential and commercial value of Galega kale by-products.

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Assessment of Atom Economy in Biogas Steam Reforming and Possible Solutions in a Biorefinery Context

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Abstract. The use and implementation of biorefineries based on natural sources or wastes is becoming more and more important nowadays, due to the global concern about some environmental issues such as carbon dioxide emissions. In that sense, the nature of these biorefineries is heterogeneous, as they can be provided with plenty of energy or material sources, using endless techniques for their sustainable exploitation. In essence, energy and materials are obtained from natural sources with the lowest environmental impact, if possible. One of the basic parameters to assess the environmental impact of a biorefinery is the atom efficiency. Thus, the higher it is, the lower emissions are released in the environment. One interesting example could be the use of biogas steam reforming to produce hydrogen, a valuable energy vector. Considering the above, the aim of this work was to assess the sustainability of this process through the quantification of atom efficiency, obtaining high values of this parameter in general (exceeding 35,70%). Thus, the combination with alternative techniques such as Fischer-Tropsch could be an interesting way to improve the sustainability of the process, with the subsequent increase in costs.

Keywords: methane steam reforming · hydrogen production · heterogeneous catalysys · membrane reactors · sustainability

1 Introduction

There is growing concern for environmental care at both institutional and personal levels globally, due to events that demonstrate the impact of climate change resulting from industrial and human actions. Phenomena such as global warming and meteorological changes have significant impacts on many regions [1]. Measures are being taken at all levels, exemplified by the UN's Sustainable Development Goals (SDGs). These measures and objectives aim to achieve sustainable industrial development in the medium and long term.

Hydrogen is considered an efficient and clean secondary energy source that has the potential to replace fossil fuels [2]. The use of biomass to produce hydrogen is currently

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seen as a promising technology that can effectively address the issues of high energy costs and environmental pollution. Emerging sectors, including domestic heating and transport, are also focusing on hydrogen as a clean energy carrier [3, 4].

Steam methane reforming (SMR) is the most common and cost-effective method for hydrogen production, accounting for approximately 50% of global hydrogen production [3–7]. SMR is an endothermic process that extracts hydrogen from methane and water molecules by oxidising the carbon atom in methane (as shown in Eq. 1). The reaction is typically followed by the exothermic water-gas shift (WGS) reaction (Eq. 2). This reaction further oxidises the carbon atom presents in the initial methane molecule, producing additional H_2 molecules [4, 8]

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \Delta H_r^\circ = 206 kJ/mol \tag{1}$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \Delta H_r^\circ = -41 kJ/mol \tag{2}$$

$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2 \Delta H_r^\circ = 165 kJ/mol \tag{3}$$

Steam reforming is a process used to produce hydrogen from hydrocarbons, specifically natural gas, and can also be applied to biogas produced through anaerobic digestion [4].

In this context, biorefineries could play a fundamental role due to their sustainable nature, offering multiple possibilities with a lower environmental impact compared to oil-based refineries. Therefore, the sustainability of a biorefinery depends on its ability to utilise all introduced or generated resources. This property is determined through complex and multidisciplinary studies, such as life cycle assessments, which cover various aspects and stages of an industrial or semi-industrial process. On the other hand, a preliminary method for determining the sustainability of a biorefinery is based on atomic efficiency. Atomic efficiency is the percentage of atoms that enter a system and are utilised, either energetically or materially. A higher atomic efficiency results in a lower possibility of emitting (possibly polluting) compounds to the environment, increasing sustainability. The sustainability of a process must be validated by various means, including energy efficiency, economic studies, etc. Atomic efficiency can provide a useful estimate of sustainability, but it should not be the only factor considered.

Atom economy is the process of minimising or eliminating the number of atoms that are not converted into the desired product [9]. It is mainly calculated by dividing the molecular weight of the final product by the sum of the molecular weights of all the reactants. This value can be determined before the start of any experiment and is usually expressed as a percentage.

2 Materials and Methods

This section will detail the two fundamental aspects of this study. Firstly, it will describe the reforming process and the configuration of the installation in which it is carried out. Secondly, it will provide an explanation and an example of the atomic efficiency calculation.

2.1 Steam Methane Reforming

Traditional steam methane reforming (SMR) must be carried out at high temperatures, typically between 800 and 900 °C and high pressures, between 10 and 25 bar. The syngas produced from traditional SMR typically contains 70–72% H_2, 6–8% CH_4, 8–10% CO and 10–14% CO_2 (dry basis)[7].

To carry out the process, as shown in Fig. 1, the gas must first be introduced into the desulphuriser in order to remove the hydrogen sulphide contained in the biogas, if this is produced in the anaerobic biodigestion process. In the reforming of biogas (specifically, methane) to hydrogen, a catalyst (usually based on Nickel on alumina as a support) is often used to facilitate the conversion of the methane contained in the biogas. This catalyst is introduced in a basket inside the fixed bed reactor, through which the mixture of steam and biogas is directed under stoichiometric conditions (usually 3:1 steam/methane ratios) [4]. The kinetics of the reaction is conditioned by the space velocity required to achieve adequate conversion to hydrogen.

On the other hand, the flue gas after the reaction will undergo different treatments, such as a condensation process in order to remove the excess steam from the reforming, opening the possibility for possible purification techniques of the hydrogen obtained such as the use of membrane reactors (Fig. 2).

Inorganic membrane reactors can achieve in situ gas separation and conversion in a single unit at high temperatures, thus promoting the efficiency of the SRM process.

Ceramic carbonate dual-phase membranes (CCDP) can effectively separate CO_2 from the CO_2-containing gas mixture at high temperatures. In this membrane reactor, the CCDP membrane separates CO_2 from the flue gas and then simultaneously reacts with CH_4 to produce H_2 and CO.

Thus, the most interesting points of such an installation are the following:

- The use of an HPLC pump to supply distilled water to the system is indispensable, to ensure the supply of the exact flow rate to provide steam to the system.
- The supply of biogas, in the right proportions according to the biogas composition of the plant, to carry out the methane reforming.
- The temperature-controlled furnace houses the fixed-bed reactor with the nickel catalyst on alumina spheres. Here the methane reforming reaction will take place.
- The condenser and gas-liquid separator to obtain a dry gas, which can be analysed by gas chromatography.
- Finally, chromatographic analysis will allow the methane conversion or hydrogen production to be determined as the reaction proceeds.

In the case of the membrane reactor, the membrane itself to carry out the purification of H_2 or CO_2 during the process.

2.2 Atomic Efficiency

Atom economy is the process of minimizing or eliminating the number of atoms that are not converted into the desired product. It is mainly calculated by dividing the molecular weight of the final product by the sum of the molecular weights of all the reactants. This

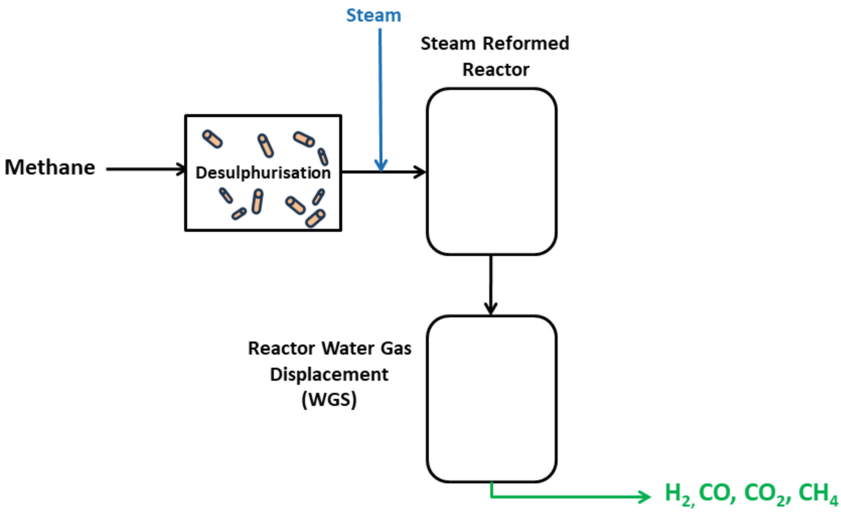

Fig. 1. Methane reforming scheme without membrane reactor.

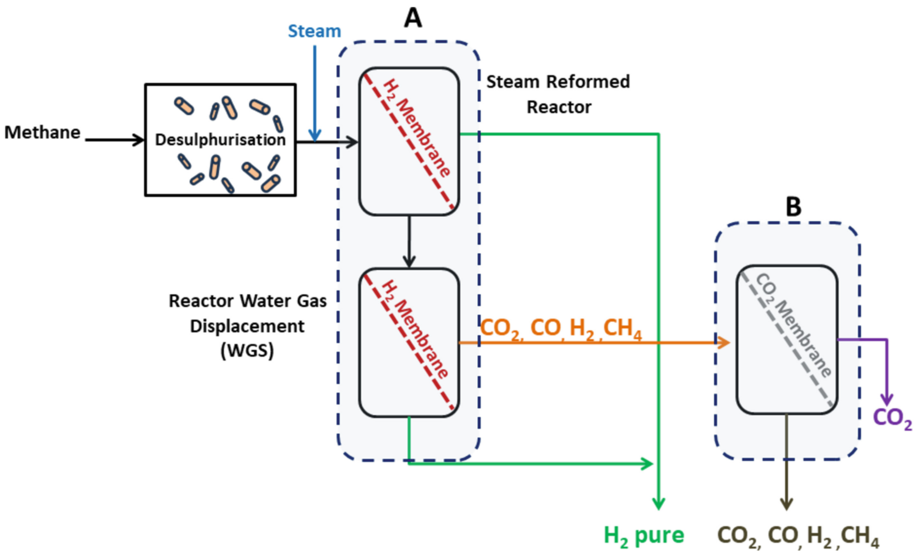

Fig. 2. Methane reforming scheme with membrane reactor.

value can be determined before the start of any experiment and is usually expressed as a percentage. In the case of industrial processes, mass percentage can be used.

Therefore, the atomic efficiency, Eq. 4, would be calculated as follows, expressed in %:

$$Atomeconomy(\%) = \frac{\sum Molecularweightofdesiredproduct}{\sum Molecularweightofreagents} \times 100 \quad (4)$$

Below is an example that demonstrates the calculation of atomic efficiency using the equation presented in Fig. 3. The equation describes a reaction involving reactants, desired and undesired products, and some reagents that do not react and become unwanted products.

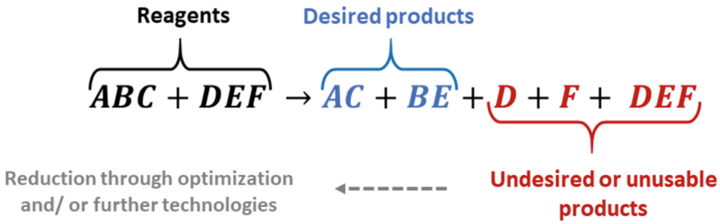

Fig. 3. Example reaction for calculating atomic efficiency.

Therefore, when considering the reactants and the desired product, Eq. 4 would be expressed as follows:

$$Atomeconomy(\%) = \frac{MW_{AC} + MW_{BE}}{MW_{ABC} + MW_{DEF}} \times 100 \quad (5)$$

3 Results and Discussion

The calculation of atomic efficiency considered the aspects shown in Fig. 2 and in this context. It is important to note that this evaluation is objective and does not include any subjective evaluations. Stage A involves steam reforming of methane followed by membrane purification of H_2, resulting in the first desired product due to its wide application in fuel cells. The remaining products, such as unpurified H_2, CO, CO_2 and unconverted CH_4, are considered undesirable. Stage B focuses on purifying CO_2 and converting it into the second desired product. Any remaining products, such as non-retained CO_2, CO, H_2 and CH_4, are considered unwanted at this stage.

The process performance and efficiency of each membrane type for hydrogen and CO_2 separation were evaluated based on previous research, [3, 4, 10]. Equation 5 was used to obtain the corresponding results (Table 1).

The table shows a high conversion of methane considering other similar studies[4].

Hydrogen separation is high, although there is a percentage of hydrogen that is not retained and becomes unwanted. The situation is more pronounced with CO_2, resulting in non-retained CO_2 becoming unwanted. Consequently, the atomic efficiency in process A is very low due to the low molecular weight of hydrogen compared to the input of reactants. To improve this situation in case A + B, introduce a further step that includes the possibility of CO_2 purification by a membrane reactor. This results in a 35.70% increase in efficiency, which is about 14 times higher than the previous case. The reason for this increase is that the desired product has a higher molecular weight than hydrogen.

This case is noteworthy due to the potential for reducing environmentally harmful gases that contribute to the greenhouse effect. Increasing atomic efficiency leads to

Table 1. Main results of this study.

Parameter, %	Results
Methane conversion	75.10
H_2 membrane separation	93.10
CO_2 membrane separation	56.93
Atom efficiency (A)	2.66
Atom efficiency (A + B)	35.70

lower emissions of pollutants into the atmosphere, promoting environmentally friendly chemistry.

This requires additional processes, such as CO_2 membrane separation, which can be used in industrial-scale methanol and urea production.

It is important to note that the remaining byproducts, such as unconverted CH_4, unpurified CO_2, unpurified H_2, CO, and water vapour, could be reused through additional techniques. This would increase the atomic efficiency beyond the current 35.70%. However, it should be considered that additional steps, such as Fischer-Tropsch, would be required, which would result in increased costs and resource usage.

4 Conclusions

Based on the information presented above, the following are the main conclusions:

- The proposed reforming process has a potential to obtain very useful products for industry, such as H_2, CO, CO_2, but especially H_2.
- Such processes can be evaluated from an economic, energetic and environmental point of view, atomic economics being a useful tool for the last point.
- The proposed systems offer an atomic economy of approximately 2% for the production of H_2 and 35% for the production of CO_2. The low efficiency in the first case is due to the low molecular weight of H_2 and the different efficiencies of the process, such as low selectivity and losses related to the separation process. In the second case, the atomic economy increases considerably due to the molecular weight of the other desired product that is added to the process.
- An increase in atomic efficiency contributes to the sustainability of the process by helping to reduce greenhouse gas emissions.
- However, the increase in atomic efficiency implies the use of additional steps such as separation, conversion, and synthesis. This results in an increase in fixed and up-front costs, as well as the need to add value to the processes.

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Teaching How to Be Ethical in Research for Final Degree Students in Engineering Degrees

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Abstract. Final degree projects (FDPs) are a challenging stage in the academic life of students, but it is also a challenge for teachers as FDPs could represent a key link between university and professional environment, including scientific research. In a way, this stage is a transition for students, where they can achieve maturity in many aspects such as critical thinking, autonomy, self-confidence, or ethics, among others, getting ready for the real world where mentorship might not be as usual as expected. In other words, FPDs (apart from the obvious academic benefit) could be an essential experience to shape different appreciated values that could help our students to make right decisions in the future. However, according to our experience, students usually present worrying lacks in many facets, including research ethics, which is the subject of this work. Thus, our goal is to show an update of our didactic unit devoted to the suitable development of FDPs, focusing on research ethics and some basic guidelines concerning different aspects such as authorship, plagiarism, the use of artificial intelligence, etc. As a result, high-quality FDPs were obtained, and the students learned to avoid ignoble practices such as plagiarism or reference lumping.

Keywords: STEM · Final degree project · Didactic unit · Plagiarism · Authorship

1 Introduction

1.1 Research Ethics

In such a changing world, where there are continuous changes in cutting edge research that present multiple realities and challenges that should be accomplished from different points of view, ethics is becoming essential to help make right decisions.

In that sense, scientific research is not unfamiliar with these challenges, with plenty of paradigmatic examples such as the use of atomic energy, genetically modified crops, cloning, etc. In any case, these are complex issues where questions posed on the foundations of research are usual. However, even at different stages of research these ethical issues can emerge, related to the most apparently insignificant task. Thus, the selection of a research topic, the experimental performance or the diffusion of results can affect

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different stakeholders, and the different options available can benefit or undermine to a greater or lesser extent. The approach to meet these challenges can be adapted to the means to obtain a certain result or the result by itself, as well as the virtue of the researcher (or group of researchers, institution, etc.) [1].

On the other hand, Final Degree Projects (FDPs) are an essential stage in the academic life of students, as it represents one of the most advanced subjects in their careers, normally preceding the obtention of a certain academic title. In other words, FDPs, which are focused on research or technical subjects, are one interesting link to the "real world", that is, students' future professional career. Normally, these projects imply a complete research work, including experimental design and performance, as well as the interpretation and diffusion of results, as well as further studies such as economic viability of a certain technology or life cycle assessment, depending on the academic level of students. As expected, there are plenty of ethical issues in this context, most of them unfamiliar for students.

Considering the above, the aim of this work was to describe the inclusion of research ethics in a didactic unit devoted to the suitable completion of FDPs in Engineering degrees (focused on energy). Thus, different ethical issues, in a transversal context, are commented, including the main results observed in FDP defense and evaluation.

1.2 Our Context

The Department of Applied Physics, which covers a wide range of courses in different Engineering disciplines, deals with an heterogeneous profile of students, with different subjects related to sustainable energy production.

Thus, 25 FDP students were considered for this study, with their main characteristics included in Table 1. As observed in this table, the FDP is an important research work, normally taking 6 months, which allows the tutors (university teachers and researchers) to thoroughly teach many aspects related to this project, including research ethics.

This work is reflected in the FDP report (with a considerable extension, as observed in Table 1), where a typical research work is carried out, including the typical sections of a peer-reviewed article: abstract, keywords, introduction, materials and methods, results and discussion, conclusions and references. As commented in following sections, many ethical issues can be inferred from these sections, which is one of the central parts of the suitable guidance in research ethics. In order to accomplish the suitable explanation and completion of FDPs, the tutors or mentors count with a didactic unit explained in previous works [2], including aspects such as safety [3], among others [4–6].

However, a new update has been carried out to include research ethics, as the lack of knowledge about this issue is considerable according to a previous test carried out by the students, as observed in Fig. 1. According to data, there was a considerable percentage of students (exceeding 80%) who did not know the relevance or significance of research ethics, being one of the most important concepts to be reinforced in FDPs.

Consequently, research ethics was included as a transversal priority in our didactic unit, as observed in Fig. 2, having a strong influence on different aspects such as safety at work (where it is obvious the requirement of safety conditions for a suitable research experience) or different content related to FDP (for instance, the ethical options for the suitable selection of a certain green technology).

Table 1. Characteristics of the students and FDPs considered for this work.

Characteristic	Value
Sex (male/female)	16/9
Age (years)	22–38
Degrees	Chemical Engineering, Industrial Engineering
FDP subject	Biodiesel and biolubricant production, biomass and bioenergy
Average FDP completion (months)	6
Average FDP content (pages)	80–100

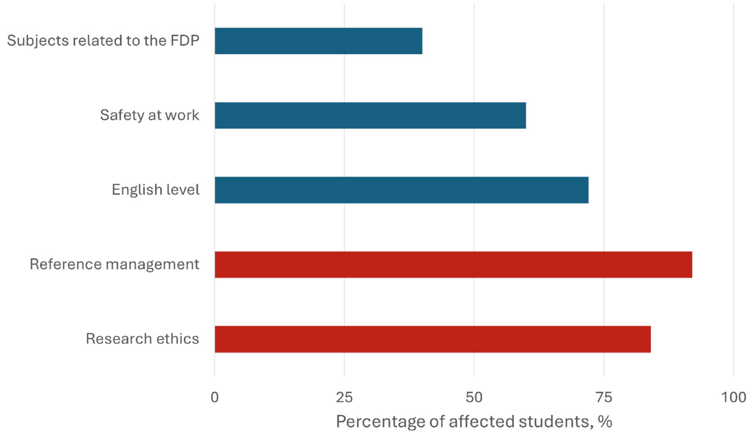

Fig. 1. Main lacks in different aspects related to the completion of FDPs.

Equally, within one of the main priorities of the didactic unit, research ethics plays an important role, having to do with different tasks such as literature review, experimental design and procedures, writing and results dissemination or critical thinking. As a consequence, the main ethical issues related to these priorities will be covered in the following section, where the main details explained to the students are included.

2 Research Ethics During FDP Completion

In our context, the main aspects related to research ethics that were covered are included in following subsections. It should be noted that ethical issues are present in almost every detail, so we are going to focus on the most relevant ones according to our experience. In order to assess some relevant aspects related to research ethics, plagiarism rate (that is, the percentage of coincidences of FDP reports compared to the literature) was compared before and after the implementation of this didactic unit.

Fig. 2. Different priorities in our didactic unit for the completion of FDPs in Engineering (focused on sustainable energy and products). Research ethics can interact with many different aspects covered in this didactic unit (see grey arrows).

2.1 Research Subject and Critical Thinking

In this didactic unit, the right selection of the research subject is also an ethical subject, where issues such as the experimental design are important, as well as the promotion of critical thinking throughout the process.

Thus, a thorough search for literature, as well as a suitable and convincing explanation about the research subject, pointing out the sustainability development promotion of biomass and bioenergy subjects, is also encouraged.

2.2 Plagiarism, Citations, Use of AI and Misleading Information

This is one of the most critical points concerning research ethics. Thus, the disadvantages of plagiarism are clearly explained to students, making differences between plagiarism (with the absence of reference citation), paraphrase, quotating, etc. In any case, the use of references (included in the text and in the final reference list) is essential, avoiding reference lumping (unnecessary accumulation of references in short paragraphs, for instance). Also, self-citation of previous works is sometimes essential to understand a certain FDP, but excessive self-citation is not recommended. In that sense, figures and tables, when necessary, should be equally referenced, and most students are not aware of this fact.

Equally, the use of Artificial Intelligence can be an interesting tool, but its improper use should be warned to students. In any case, the use of AI is not necessarily bad (it can help the student to carry out estimations or calculations), requiring its reference quotation when necessary and avoiding its abuse in the FDP report.

2.3 Results and Discussion of Results

This is one of the most important parts of the FDP report, requiring a rigorous statistical treatment of the results (especially when discarding data) in order to avoid their biased interpretation. Thus, it is essential the acceptance of "negative results" (those against the initial hypothesis).

Also, the right explanation of results (which should be clear and concise to avoid misleading explanations) is equally important, presenting not only the references to the literature that support our results, but also the contradictory trends observed. In order to avoid misleading sentences, it is important to get a high English level (one of the main challenges according to Fig. 1). Otherwise, our students tend to read research articles in English and write initial sentences in Spanish, using software to translate it into English and finally revising and making changes to this final text. Essentially, this practice is similar to the rumour experiment where a chain of people disseminate a certain message, being completely different at the end of the chain. In a sense, we recommend as much as possible to carry out the whole process in English, avoiding translators and reducing the chain in order to reduce distorted messages obtained from the cited researcher.

3 Results and Interpretation

The main results obtained once the didactic unit (including research ethics) was completely implemented were interesting, as problems related to plagiarism were totally avoided (the evaluators have a computer tool that allows them to check plagiarism), not detecting coincidences with the literature above 20% (which is the general criteria selected to determine if a certain work was plagiarized).

Thus, prior the implementation of this didactic unit, plagiarism (before sending the final draft to be evaluated) was on average 34%, with extreme cases where 76%, which was unacceptable in any case, requiring fundamental changes in this report, with the subsequent waste of time by the student and tutor (who has to re-check the final report). Once the didactic unit was implemented, this plagiarism rate was 18%, most of it located in "Materials and Methods" section, which is difficult to be written in different ways, especially when previous works have been carried out and published using the same methods and apparatus. That means that the "Introduction", "Results and Discussion" and "Conclusion" sections were practically original, which is interesting as it is normally the most differentiating parts of a scientific work.

On the other hand, fostering rigor in FDPs led to high-quality reports where criticism by evaluators concerning the lack of coherence or misleading content was less frequent.

Additionally, these works were positively rated, with an special mention (in general) about suitable article referencing and the lack of misleading information or sentences, increasing the sense of rigor in FDPs.

Nevertheless, in our opinion, the most interesting outcome was the final awareness of our students about research ethics, which will be used not only in research fields but also in different professions where reports have to be carried out permanently, for instance, or other management positions where important ethical decisions should be made having to do with intellectual property, environmental protection, reconciliation of work and private life, etc.

4 Conclusions

The main findings inferred from our experience were the following:

- Most FDP students are not aware of the main ethical issues related to research practices. Thus, unethical practices would be, in most cases, due to lack of knowledge about this subject.
- According to the above, research ethics should be an essential and transversal part of a didactic unit of this nature in order to give future professionals a suitable tool to assess different ethical problems.
- According to our experience, different aspects were covered in our didactic unit devoted to FDPs (focused on energy production), like the avoidance of plagiarism or reference lumping, most of them applicable to other research disciplines and their future professional careers.
- As a consequence, high-quality works were carried out, with a considerable improvement in citation practices (avoiding repetition or lack of required references) and a low percentage of plagiarism (below 20%) compared to published literature.
- One of the main objectives of this approach was to foster ethical awareness in FDP students, not only applied to research but also to every aspect of their future professional development.

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Exploration of Mineral Resources – Sustainability Perceived by the Population

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Abstract. The mineral resources sector has faced intense social and environmental scrutiny in recent years. Under the argument of lack of information and lack of transparency of the projects, the populations of the territories covered by projects in the mineral resources sector (mines and quarries) have consistently increased the degree of contestation and objection.

This paper, analyzes the responses of a population in a survey carried out between December 1, 2023 and January 31, 2024, seeking to understand how the population understands the mineral resources sector, its exploration in the parish territorial space, as well as the social, environmental, economic and cultural perspectives in the context of a broad corporate social and environmental responsibility policy.

In this paper, a first set of results are analyzed and advanced, where it is possible to verify that the population understands the need to explore mineral resources, pointing out that the biggest problem with quarries is the destruction of the landscape and the environment around them.

Keywords: Sustainability · Mineral resources · Population survey

1 Introduction

The mineral resources sector, and consequently the extractive industry, have in recent years been the target of social scrutiny and strong environmental contestation [1–6]. Given the previous framework, the study and analysis of the Social Operating License (SLO) of companies in the sector and the respective social responsibility as well as the environmental sustainability of exploration of mineral resources attest and confirm the pertinence and relevance of the theme under analysis in this article.

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Some studies point to social factors and/or violation of human rights as reasons for the growing scrutiny and social conflict of projects and companies extracting mineral resources [1, 3, 5–7]. During the last two decades, society has become more concerned about environmental and social issues, and this has forced companies to redefine their strategy [8]. The effects of public interest for a cleaner environment, the pressure of groups that have negatively targeted the mining sector at international levels, and the introduction of environmental legislation have contributed to raising overall environmental awareness. Civil society has started to claim more practical sustainability that endorses other practices than the simple publication of greenwashing reports and manuals. According to [1], there is a growing number of conflicts related to natural resource extraction, which can be seen as part of a general trend in Latin American countries. In many countries, people who are raising their voices against extractive projects are increasingly under threat, as several reports show. These reports (Michel Forst [9], Frontline Defenders [10], Global Witness [11]) highlight that restrictions on the operational space of human rights defenders are particularly severe in the extractive and natural resource sectors. Still, according to [1], land and environmental defenders are part of the larger group of human rights defenders, which comprises “people who, individually or with others, act to promote or protect human rights peacefully”. Land and environmental defenders, specifically, are active in areas such as mining and resource extraction, agribusiness, water resources and dams building, forestry, poaching, fishing, wind energy, or land grabbing.

According to [2], in a world where we are fast approaching climate and biodiversity tipping points, a widening range of stakeholders are demanding a say in the way things are done. Nevertheless, companies conducting exploration, extraction and processing operations are falling short of societal expectations and of successfully ameliorating their negative impacts. Their approaches to Corporate Social Responsibility (CSR), intended to ensure that value is created for a wide range of stakeholders, not just those with a financial stake in the enterprise, can be reactive, ill-informed, short-term and superficial. This leads to controversy and discord, as extractive operations continue to have deleterious impacts on the wellbeing and quality of life of local and global communities. It also has consequences for perceptions regarding the legitimacy of companies in the sector and whether ‘permission’ is granted so they can continue their operations, in specific SLO.

This article intends to show preliminary results of the study carried out, which aims to help understand how a population exposed to the extraction of mineral resources perceives the extraction activity, in the context of socio-environmental sustainability, seeking to identify ways to resolve potential conflicts, and in this way contribute for a sustainable development base for the mineral resources sector, contributing to coexistence between local communities and companies.

2 Context and Study Area

2.1 Study Location and Characteristics

The Parish of Alqueidão da Serra (established in 1615), is a parish belonging to the Municipality of Porto de Mós, in the district of Leiria. Located in the Serra de Aire, it is partially included in the Serra de Aire e Candeeiros Natural Park. In the region, limestones from the Middle Jurassic predominate, which in the past and currently allowed the opening and exploitation of several quarries for various purposes. As Fig. 1 shows, the parish is located in the central region of Portugal, and has an area of 21.27 km^2, with 1549 inhabitants (2021 census) [12].

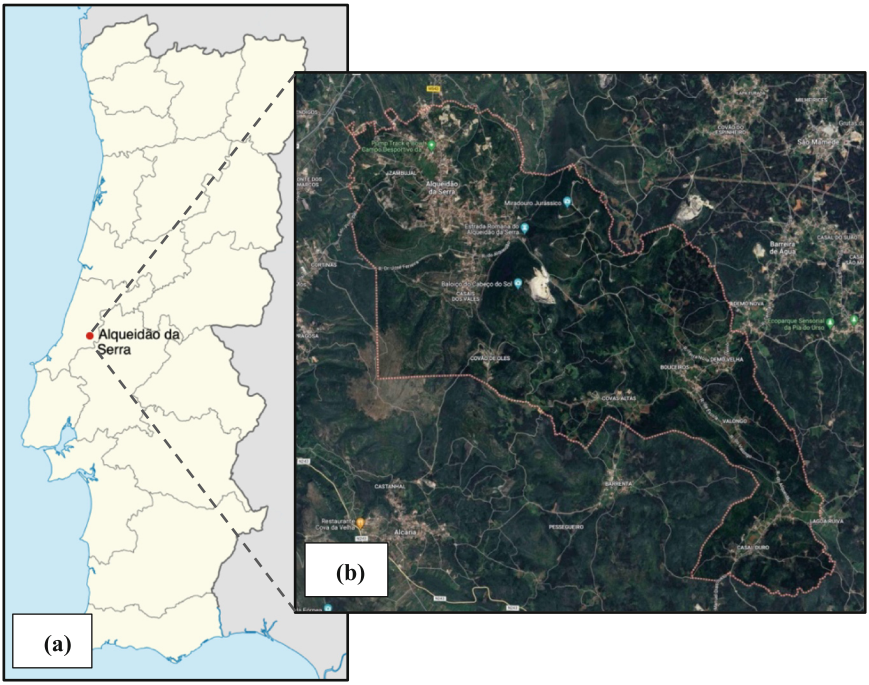

Fig. 1. **(a)** Geographical framework of the parish of Alqueidão da Serra, adapted from https://pt.wikipedia.org/wiki/Alqueidão_da_Serra; **(b)** Configuration of the parish of Alqueidão da Serra, with boundaries delineated with a red line. Photography adapted from Google Maps, with the approximate central coordinates of the village center being 39°36′57.1″N 8°46′55.2″W.

According to what is described on the website of the Parish Council of Alqueidão da Serra, the "*(…) immense exploration and cutting of limestone for sidewalks (…)*" did not survive the economic crisis of 2011. "*Activity with strong economic impact over the last three decades. Alqueidão was the capital of Portuguese sidewalks.*" [13].

In Fig. 2, it is possible to see the village in aerial photography, with the identification of the two main "cores" for the exploitation of limestone for paving (black, blue and grey) in relation to the village. In Fig. 2, highlighted with the yellow oval (roughly to the southwest) the "core" of Moinhos and Zambujal, highlighted with the blue oval (roughly to the northeast) the "core" of Cumeira and Vale das Matas. In the parish of (roughly to the northeast) the "core" of Cumeira and Vale das Matas. In the parish of Alqueidão da Serra, there is also a Class 2 quarry for the exploitation of limestone for civil construction and industry.

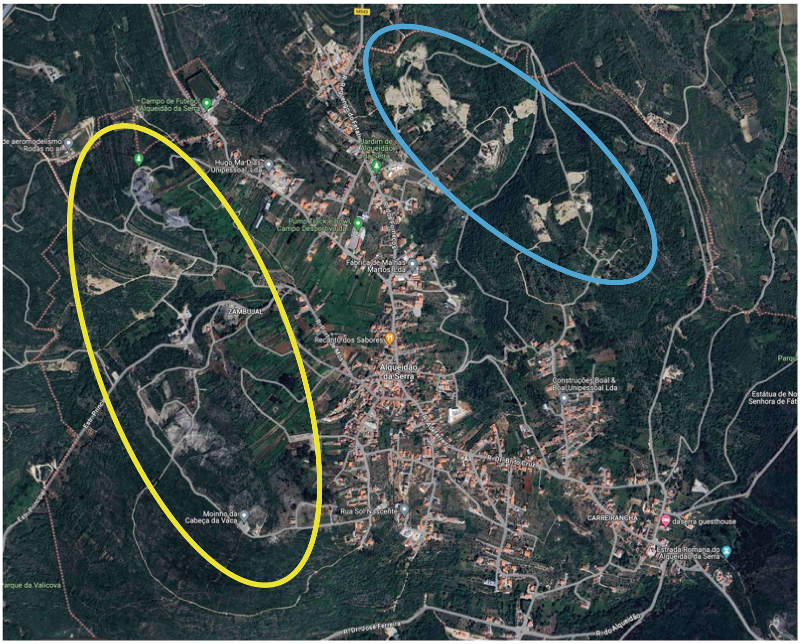

Fig. 2. Location of the main "cores" for the exploitation of paving stone in relation to the village of Alqueidão da Serra. In the yellow oval, Moinhos and Zambujal area. In the blue oval, Cumeira and Vale das Matas area. Photography adapted from Google Maps, and the approximate central coordinates of the village center are 39°36′57.1″N 8°46′55.2″W.

2.2 Methodology

To carry out this study, a questionnaire was carried out in the form of a survey throughout the inhabitants of the parish of Alqueidão da Serra. The questionnaire began on December 1, 2023 and ended on January 31, 2024, and was made available to the population in two different formats, paper and digitally (by Google Forms platform).

The use of these two supports aimed to increase access and coverage of the questionnaire, mainly with regard to the elimination of possible info-exclusion factors on the part of the target population in relation to new IT technologies, namely, difficulty in accessing and/or inability to browse the internet.

The survey consists of eighteen questions grouped thematically. After some questions characterizing the respondents (gender, age and academic background), questions of a general scope are asked, followed by questions of a social, environmental, economic and historical nature.

Regarding the digital survey, was activated an option that guaranteed that each email address could only respond once to the questionnaire, and the option of not identifying the origin of the response was also activated, what means that it was guaranteed that the responses collected were anonymous. Likewise, the questionnaires carried out on paper were also completely anonymous, and in the work of distributing and collecting surveys on paper, a check was made with the respondent to ensure that had not already responded in a digital format.

The size of the universe studied is 1 327 people. In this study, was considered the entire population of the parish aged 18 years or over [12].

2.3 Results and Analysis

As a result of the work carried out, 134 surveys were collected in digital format, and 76 in paper format, totaling 210 completed surveys. Taking into account the size of the universe, for a 95% confidence level, and a sampling error of 6.21%.

Characterization of the respondents. The sample of respondents is divided into 110 responses from women (52%) and 100 responses from men (48%), which are distributed by age according to the graphic in Fig. 3.

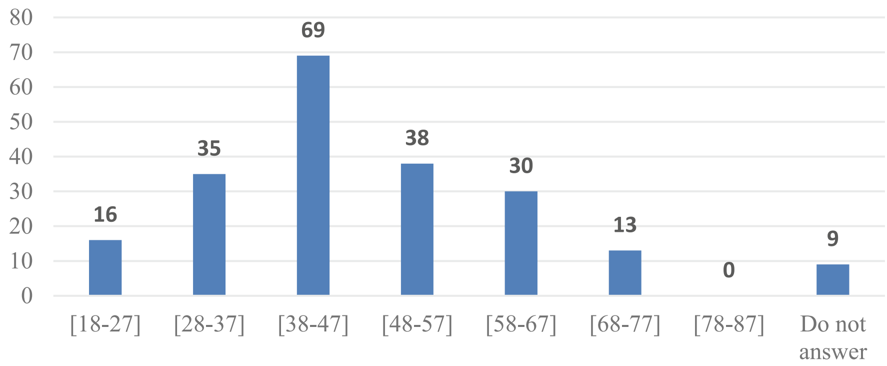

Fig. 3. Age distribution of respondents (age classes in "x" axis).

In Fig. 3 it is possible to see that the most representative age group is the class.

[38–47] with 69 respondents (≈33%), followed by the class [48–57] with 38 (≈18%), class [28–37] with 35 (≈17%), class [58–67] with 30 (≈14%), class [18–27] with 16 (≈8%), class [68–77] with 13 (≈6%).

The respondents' level of education was also characterized, obtaining the results shown in the graphic in Fig. 4. The graphic shows that around 53% of respondents have higher education, 22% have up to 12th grade, 11% have up to 9th grade, 6% have up to 6th grade, and 6% have the "former 4th class".

General Questions. One of the questions analyzed based on a general perspective of the mineral resources sector was "Do you consider it necessary to explore mineral resources (for example, quarries)?".

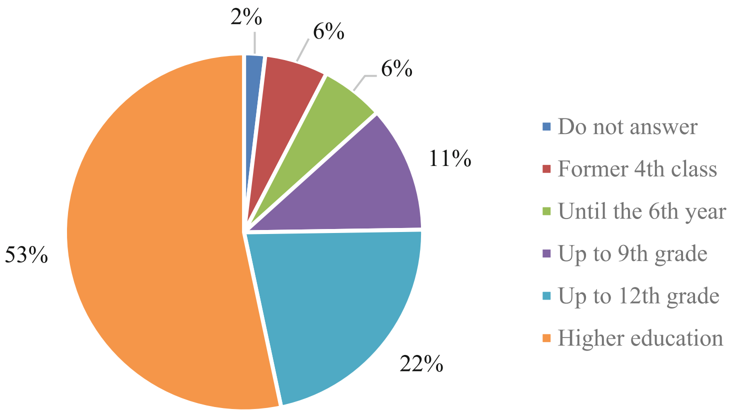

Fig. 4. Education level of the sample of respondents.

By asking this question in the inquiry, it does not ignore the current social context in Portugal regarding a broad protest against mineral resource exploration projects, as well as mineral resource prospecting and research projects. Thus, indirectly, the question may bring lines of understanding and help to understand how the population in question is interpreting and/or absorbing the general context of contestation. In this context, it is considered relevant to understand whether the aforementioned social protest is reflected in the opinion and/or perspective of this population, in relation to the social need to explore mineral resources.

The Table 1 shows that 198 (94%) respondents answered **Yes**, and only 12 (6%) of respondents answered **No**. It can therefore be seen that the vast majority of respondents consider it necessary to explore mineral resources.

Table 1. Answers obtained in the question "Do you consider it necessary to explore mineral resources (for example, quarries)?"

Question	Answers		
	Yes	No	*Do not answer*
Do you consider it necessary to explore mineral resources (for example, quarries)?	198 (94%)	12 (6%)	0 (0%)

The question, posed in a simple and direct way, is premised on understanding if they consider it to be important and necessary to explore mineral resources, from a generic perspective and taking into account the context of social and/or technological development of today's society.

Exploration of Mineral Resources. Regarding the exploration of mineral resources itself, one of the questions asked was "What is the main problem/annoyance you see in a quarry?". In this question, respondents should select one of five possible options, as shown in Table 2.

Table 2. Possibilities of answering the question "What is the main problem/annoyance you see in a quarry?", and respective results obtained

	Options	Answers	
		Number	%
1	Destruction of the surrounding landscape and environment	169	81
2	Source of dust emissions	23	11
3	Lots of heavy traffic, causing noise and vibrations	10	5
4	They do not bring economic benefit to the locality	2	1
5	They are too big	3	1
6	*Do not answer*	3	1

The results obtained in Table 2 clearly show that the main problem/annoyance that respondents see in a quarry is the "Destruction of the surrounding landscape and environment", with 169 responses (81% of the total of respondents). Around 11% of respondents (23 answers) consider that the main problem of quarries is that they are a "Source of dust emissions", 5% (10 answers) consider that the main problem of quarries is "Lots of heavy traffic, causing noise and vibrations", 1% (3 answers) say that the main problem with quarries is "They are too big", and finally, 1% (2 answers) say that the main problem with quarries is "They do not bring economic benefit to the locality".

The results obtained in the question "What is the main problem/annoyance do you see in a quarry?", reliably indicate that the population surveyed is not unaware of environmental issues related to the exploitation of resources. With 81% of responses (4.5 times more than the sum of all other responses), they demonstrate concern about the environmental impact that the exploitation of mineral resources causes, specifically with the destruction of the landscape.

Analyzing this question with the results obtained in the question "Do you consider it necessary to explore mineral resources (for example, quarries)?", it can be said that the acceptance of the need to explore mineral resources by the population does not leads to omitting and/or ignoring the environmental impacts that quarries have.

Social Responsability. In the social responsibility of the companies operating quarries, bearing in mind that this topic is a subject that can be said to be relatively recent in the context of companies operating mineral resources, it is important to understand whether the population under study sees this aspect as relevant. Thus, the question was "In your opinion, do companies that operate quarries have or can have social responsibility in the locality where they are located?", as shown in the Table 3.

The results obtained in Table 3, 186 (89%) respondents said **Yes**, and 22 (10%) respondents said **No**.

The analysis of the answers obtained to this question shows a clearly positive understanding of this matter on the part of the sampled population. Given this understanding, it is important to explore the concrete understanding on how to materialize corporate social responsibility, so the answers obtained in the subsequent questions of the survey will be analyzed at this level (but not present in this paper).

Table 3. Answers obtained to the question "In your opinion, do companies that operate quarries have or can have social responsibility in the locality where they are located?"

Question	Answers		
	Yes	No	*Do not answer*
In your opinion, do companies that operate quarries have or can have social responsibility in the locality where they are located?	186 (89%)	22 (10%)	2 (1%)

History and Information. As previously mentioned, the survey also addresses the history and information of the quarries. It was considered relevant to try to understand the extent and internalization of the mineral resources sector (ornamental/sidewalk sub-sector) in the surveyed population (which will not be addressed in this paper), as well as trying to understand the population's position in relation to the existence and need for information about explorations (quarries) in their locality. In this context, it was asked "Do you think it would be important to have access to information about quarries close to where you live (within a radius of 5 km)?", as can be seen in Table 4.

Table 4. Answers obtained to the question "Do you think it would be important to have access to information about quarries close to where you live (within a radius of 5 km)?"

Question	Answers		
	Yes	No	*Do not answer*
Do you think it would be important to have access to information about quarries close to where you live (within a radius of 5km)?	186 (89%)	22 (10%)	2 (1%)

The results obtained in Table 4, 186 (89%) respondents said **Yes**, and 22 (10%) respondents said **No**. The results clearly show that the surveyed population would like to have information about the quarries that are located close to the locality.

It should be noted that, although the integrated analysis of the data collected in the survey is still ongoing, it is possible to confidently state that regarding the type of information that the population considers important to have access to, approximately 73% of respondents agree that it is important have access to environmental information, around 58% of respondents agree that it is important to have access to socioeconomic information, and around 59% of respondents agree that it is important to have access to historical and cultural information (although the agreement expressed by the respondents is expressed in different degrees).

Similarly to the joint analysis carried out in the question about Exploration of Mineral Resources, also in this aspect, it can be said that the acceptance of the need to explore mineral resources by the population does not mean that the population does not consider the need to know more and have more information about the quarries.

For an integrated analysis of the four issues addressed in this paper, it is considered important to look at Fig. 4, relating to the academic training of the population, where it can be seen that 75% have completed the 12th grade or more, and where 53% have higher education degree. It is considered that this aspect helps to explain the level of demanding found in the answers to the questions, and from the outset, it helps to explain why there are such expressive answers with percentages above 80% in all questions.

It is also considered relevant to verify that, despite the openness and acceptance on the part of the population regarding the need to explore mineral resources (Table 1), there is a very clear perception of the environmental impacts that may be associated with the extraction of mineral resources (quarries) mainly with regard to the landscape impact (Table 2), from which it is clear that there is no relativization or reduction in the importance of environmental issues in relation to the need to explore mineral resources.

Similarly, with regard to the issues of social responsibility (Table 3) and history and information (Table 4), the population's understanding goes in the direction of demand and need.

In order to provide a broader view of the population's understanding (and as previously mentioned, the integrated analysis of the data collected in the survey is still ongoing), it is possible to confidently state that the preliminary results to questions such as "Do you think it is possible to reconcile the exploitation of quarries while protecting the environment?" or "Do you think that quarrying in your locality is, or was, important economically and/or socially?" they received the majority of the population's agreement (although expressed in different degrees of agreement).

Given the preliminary results on these two questions, it would be possible to interpret that there will be a "community notion" (a prudent and cautious interpretation of the trinomial social/environmental/economic need), that is, voluntary internalization of notions and concepts of sustainability. Saying that, it will be important to verify the role of the population's academic training, if it becomes viable during the integrated analysis work currently underway, since, as previously mentioned, around 75% have completed the 12th grade or more (53% have higher education degree).

3 Conclusion

From the analysis carried out in this paper, it is possible to draw some conclusions, taking into account the characterization of the sampled population and the themes addressed. However, note that when collecting responses from a community through surveys, there is always a margin of subjectivity. In this sense, the authors of this study, in order to minimize the subjectivity inherent in a study of this nature, in the survey carried out asked questions that verify answers to previous questions (common methodology in this type of fieldwork). Additionally, the data processing carried out is done with the help of a computer tool that allows cross-referencing of answers given by respondents.

Statistically, the surveys carried out present an associated error of 6.21% for a 95% confidence interval, in a population sample of 52% of women and 48% of men, where 75% had a 12th grade or higher. It was concluded that the vast majority of respondents believe it is necessary to explore mineral resources (94% of the population according to the Table 1). Bearing in mind the current social protest regarding mineral resource projects, it is somewhat surprising.

When asked what was the main problem/ annoyance caused by a quarry, the vast majority of the population (81% according to the Table 2) responded that it was the destruction of the surrounding landscape and environment, so it is possible to say that somehow the community recognizes the existence of environmental impacts. Also, it is possible to conclude that in relation to the topic of Social Responsibility and the need for information about quarries, the vast majority of the population understands that companies that explore mineral resources have social responsibilities towards the population of the locations where they are located (89% of the population).

It is important to mention that the preliminary results of the analysis of the survey results allow us to confidently state that the population agrees that it is important to have access to environmental (78%), socioeconomic (58%), and historical and cultural information (59%). Likewise, the majority of the population agrees that it is possible to reconcile the exploitation of quarries with environmental protection, as that the quarries exploitation in the locality is or was important economically and socially.

It will be important to understand in an extended analysis work, when analyzing the remaining questions of the survey (as mentioned in the methodology subchapter, the survey carried out had eighteen questions), what is the role of the historical perception of the activity of exploring mineral resources in the population, and in this context assess the possible existence of a collective memory. In the same line of reasoning, it is considered relevant to develop a methodology that is capable of predicting and/or estimating the possible existence of a NIMBY effect (not in my backyard).

The preliminary results analyzed in this paper open doors for future analysis and specification work in terms of attributing responsibilities in the various themes covered (social, environmental and information), social responsibility measures, environmental measures, or others.

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Exploring Sustainable Dynamics in Urban Commerce

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Abstract. This chapter delves into two distinct categories of public/collective spaces that significantly impact metropolitan dynamics, albeit differing vastly in their modes of utilization, temporal and spatial characteristics, planning processes, motivational factors, and user freedoms. The first category encompasses macro-artifacts, large, peripheral shopping centers, intricately linked to major infrastructures and highway intersections, structured around regional polarization principles. The second category encompasses a myriad of micro-artifacts, including street vendors, mobile bars, clandestine dining spots, garage sales, impromptu events, artistic interventions in unconventional spaces, pop-up stores in abandoned buildings, makeshift cinemas in parking lots, and self-managed gardens on vacant plots, among others. This chapter endeavors to explore the intricate interplay between these seemingly contrasting logics in contemporary urban development. It examines how the appropriation, reconfiguration, and reinterpretation of public space at a metropolitan scale are shaped and influenced by the presence of these two categories of commercial spaces. Ultimately, the discussion highlights the pivotal role of these logics as transformative agents in urban planning, particularly in the reorganization of the public space network, serving as catalysts for profound societal change.

Keywords: public/collective spaces · shopping centres · intermittent practices

1 Introduction

This chapter highlights the crucial role that commercial and recreational spaces play in the analysis, organization, design, and improvement of metropolitan public areas. Situated within the ongoing discussion about the relationship between city dynamics, commerce, and social change, it examines two contrasting models of public and collective spaces. By comparing these models, the chapter argues that commercial spaces are vital for understanding modern transformations and can drive significant societal shifts when used strategically in urban planning. It calls for a critical evaluation of their limitations and innovations, moving beyond traditional urban planning approaches.

At the heart of this discussion is the recognition of the deep interconnection between urban spaces and commercial environments. The chapter advocates for a comprehensive

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approach to city design, suggesting that commercial planning should not be driven solely by economic factors but should be integrated into broader urban design considerations. It proposes that cities should be designed not just for commerce, but with commerce, facilitating a synergy between commercial activities and social life in urban settings.

In light of significant social, economic, and technological changes, integrating commerce and its spatial forms into urban planning is becoming increasingly crucial. This requires rethinking and reinterpreting commercial environments to reflect the flexibility and dynamism of contemporary social and economic processes. Changes in space utilization patterns, such as the rise of remote work and the shift towards temporary services rather than permanent ownership, underscore this need. Advanced mobile communication technologies and widespread social networks further highlight this trend, contributing to a culture where time is fragmented into numerous "present moments" [5].

The evolving nature of commerce challenges the conventional view of cities as stable and static. These changes fundamentally alter established patterns of urban space use and social interaction, leading to new urban practices and configurations. As a result, the traditional boundaries between public and private realms, physical and virtual spaces, and economic and political spheres become increasingly blurred. This fluidity creates a landscape of ongoing possibilities and multiplicities, capturing the essence of the contemporary city as a dynamic and ever-evolving entity.

2 The Evolving Landscape of Retail and Leisure Spaces

2.1 From Macro Shopping Centres…

Examining macro formats such as shopping and entertainment centres (see Fig. 1) prompts critical inquiry into their role within contemporary urban landscapes. [3] Do these centres contribute to the construction of the cityscape, or do they engender environments steeped in hyper-reality, as posited by Koolhaas and others? [13] Might they serve as catalysts for the emergence of new urban spaces, echoing the sentiments of Alex Wall [14] and Norman Klein? [8].

In the digital age, despite the proliferation of online interactions, the need for physical spaces for face-to-face encounters persists, underscoring the enduring importance of communal gathering spots within the evolving urban fabric. [9] Territorial legibility, as advocated by Manuel de Sola-Morales [12] and Mirko Zardini [15], remains integral to navigating increasingly complex urban environments.

The proliferation of large commercial hubs in peripheral areas has fundamentally transformed the European city, evolving it from a mere dormitory to a vibrant nexus of commerce, leisure, and relaxation. This expansion not only alters the traditional flow of urban life but also catalyzes both fragmentation and concentration within commercial landscapes. These developments underscore the dual processes of dispersion and aggregation reshaping urban commercial dynamics. [10].

The contemporary shopping center transcends its conventional role, evolving into a multifaceted node within urban mobility networks. [11] Integrating an array of functions, services, and recreational opportunities, these centres become integral components of everyday life, blurring the boundaries between residential, commercial, and recreational spaces. [7].

Moreover, recent advancements in e-commerce and mobile technology have precipitated a metamorphosis of these heavy commercial entities. [6] As physical stores increasingly serve as experiential showcases for brands, the urban retail landscape undergoes a paradigm shift. This transformation is exemplified by flagship stores of global brands like Apple, Nike, and Ikea, which prioritize immersive customer experiences. Additionally, the integration of amenities such as healthcare facilities, hotels, and theme parks within shopping centers underscores a shift towards experiential, recreational spaces.

In essence, the evolving landscape of heavy commercial formats reflects a convergence of physical and digital realms, fostering experiential retail environments that redefine the traditional notion of commercial spaces within the contemporary city.

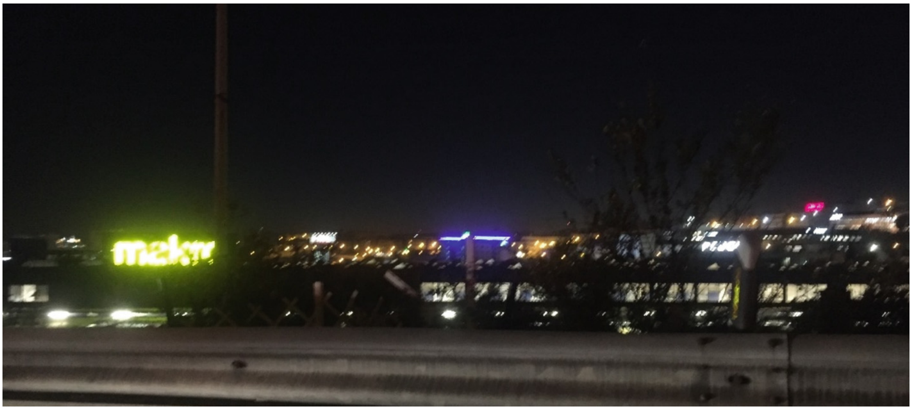

Fig. 1. CRIL and Cabos d'Ávila intersection, shopping centres in the back, (Pedro Bento, 2023)

Fig. 2. "Hiper Snack bar Canecão" Foodtruck, Lisbon Metropolitan Area. (Alessia Allegri, 2023)

2.2 To Micro Artifacts

However, within this significant push of large shopping and entertainment facilities undergoing transformation due to the internet and new technology, another concept of commerce is thriving, associated to a different use of public space (see Fig. 2).

Micro artifacts and commercial happenings, characterized by being 'light', temporary, fleeting, less prominent, and devoid of a strictly architectural definition, serve as effective examples of the present trend [1]: the activation of novel modes of perception, the pop-up phenomenon, Bauman's concept of "fluidity", flexibility, adaptability, and opportunism [4]. In many cases, these also involve interactive and participatory attitudes, collectively contributing to diverse and engaging experiences in the urban space.

This extensive array of informal commercial spaces, characterized by their temporary and sharing nature, aligns with what Allegri and Ochoa term "Intermittent Practices" in their project titled "Intermittent Lisbon: Temporary uses and sharing practices in the adaptive city" [2]. Operating within both public and private domains, Intermittent Practices manifest through temporary actions, delineating spaces, commodities, and services intended for shared use and have the power to transform our built environment.

Among the various Intermittent Practices dedicated to commercial exchange, food trucks stand out in many places. These are vehicles equipped to quickly cook and sell food at a low cost. Another form of temporary commercial exchange is the car boot sale, where private individuals come together to sell a variety of goods directly from their car's trunk.

Much more of a North American concept, the "garage sale" is an informal event for the sale of used goods by private individuals, in which sellers are not required to obtain any kind of business licenses or collect sales tax. The idea has moved beyond the individual front yard or garage and now includes neighbourhood sales. A way to get rid of the excess and superfluous without having to throw it away, and above all, a moment of conviviality and meeting of many residential area, where the meeting point for the community are, many times, limited.

The resurgence of street markets, including variations like night markets and farmers' markets, underscores the resilience of this form of temporary commerce. Beyond economic transactions, these markets contribute to the revitalization of urban areas and provide platforms for promoting healthier and more sustainable lifestyles. The emphasis on local and organic products aligns with the growing interest in supporting regional economies and sustainable practices.

In the case of Fruta Feia, the consumer Co-Op focusing on misshaped produce, there is a creative solution to minimize food waste while simultaneously fostering community engagement. The use of vacant spaces for product distribution adds an element of adaptability to the initiative.

Food trucks, car boot sales, garage sales, and street markets represent diverse forms of Intermittent Practices, each contributing to the creation of unique urban experiences. These practices not only offer economic opportunities but also foster community interaction and a sense of conviviality. The informal and temporary nature of these commercial exchanges provides a refreshing contrast to more conventional retail models.

The presence of many adapted vans, like Marcia Borges' Beauty Van and the Bread Van delivering fresh bread, that roam the streets in towns and cities across the metropolitan area of Lisbon, highlights the mobility aspect of these commercial practices. By bringing services directly to the streets, these vans contribute to the synchronization of commercial rhythms with urban rhythms, making commerce a more integral part of everyday life.

All these kind of commercial spots, that go beyond physical spaces or built typologies, synchronizing commercial rhythms with urban rhythms and the trajectories of everyday life, shape spaces and create new urban articulations, offering us an alternative model of public spaces in the metropolitan areas.

Garage sales or street vendors alone cannot generate evident spatial changes, but the repetitions, juxtapositions, combinations, and collisions of people, places, and activities create a new condition of spatial, social, and cultural fluidity that has the power to create a invisible network of public and sharing spaces, using the existing public space of the peripheral city as a support, and giving it the strength and character of a place of urbanity and sociability.

3 Conclusion

In recent years, urbanized metropolitan areas have witnessed notable shifts in the landscape of commercial spaces and consumer behaviors. While the retail scene of the past could be summarized with simplicity, contemporary retail demands a nuanced understanding, guided by the principle that "everything is and must always be new." Among the myriad formats that have emerged, two distinct categories stand out: the 'macro objects' embodied by vast shopping and entertainment complexes, and the 'micro objects' comprising a diverse array of temporary retail venues.

The divergent logics governing their design, location, presentation, and operations illustrate contrasting approaches to urban and territorial space. Yet, both forms of commercial spaces underscore their pivotal role in shaping and animating metropolitan public realms. Conceiving them as a network of heterogeneous spaces suggests the existence of a multifaceted public realm capable of enriching public life in contemporary urban peripheries.

On one hand, the proliferation of large shopping malls and 'macro materials' has elevated nodes, access routes, and their environs as vibrant public spaces. The notion of 'collective space' (privately owned yet publicly accessible) has gained complexity, expanding the potential for these facilities within an extended urban network. The diverse functions and typologies within new shopping malls may correspond to a greater diversity of public spaces, both in function and management.

On the other hand, intermittent commercial practices have revitalized overlooked or undervalued spaces, imbuing them with newfound potential and significance. These practices serve as experimental and transformative agents, testing design and policy frameworks while reshaping the geography of 'centralities' and 'peripheries,' fostering greater equity and access to public space.

By catalyzing dynamic spatial, social, and economic interactions, both macro and micro objects contribute to the emergence of vibrant urban hubs. They highlight the imperative of infusing commercial spaces with a renewed social purpose, aiming to enrich urban life through hybrid and synergistic approaches that foster reciprocal influences between city and commerce.

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Design of Pyrolysis System to Convert Waste Plastic to Fuels

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Abstract. The conventional recycling technology to process waste plastic, mechanical recycling, is not suitable to recycle waste thermoplastic with high content of contamination. Pyrolysis is a promising technology since it can convert into valuable products, such as fuels and monomers. This study focused on the design of the pyrolysis equipment for waste plastic based on polyolefins. The feeder of waste plastic is a worm screw conveyor that will be in a pre-heating system. The batch reactor has support for catalyzer and can operate between 300 up to 600 ºC with attached induction system for heating. The output flows into condenser in series to separate two liquid phases and gases, depending on its boiling point. The 3D model was done with SolidWorks, control system modelled in CADe SIMU and particle simulation with FloXpress.

Keywords: pyrolysis · plastic recycling · pyrolytic fuels

1 Introduction

Plastics are materials that are widely used throughout the world due to their versatility, durability and low cost. They are used in a wide variety of products, from food and beverage packaging to automobile and electronic components. However, the use of plastics has also raised environmental concerns, as many types of plastics are difficult to recycle and can take time to decompose in nature [1]. Disposal of waste plastic in landfills causes environmental and operational problems, and the incineration is not an alternative since it produces high emissions to air, still need landfill for not incinerated component and it is not material efficient, in the circular economy point of view.

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The recyclability of plastics is one of the advantages, but their multiplicity of functions also puts them in the position of high contamination and easy to discard by the consumer and industry, increasing the difficulty of recycling. Among the technologies of recycling, pyrolysis is one of the recycling technologies, a tertiary recycling technique. It is a thermal decomposition of polymers that occurs in the absence of oxygen or limited amounts of oxygen at high temperatures, normally at temperatures between 300 and 600 °C, breaking down the polymers into smaller molecules. Depending on the temperature and other operational conditions of the process (pressure, flow rate, input of raw material, heating speed, residence time, etc.), mixtures of solids, liquids and other products can be obtained as well as gases of different proportions and different compositions [2].

It has the potential to be a useful technology for waste plastic management for an increase in the product value chain, but there are still major challenges to be addressed. For example, it is necessary to develop efficient and economical techniques to separate the basic components of pyrolysis products, and it is also necessary to adopt a careful approach to the management of exhaust gases and other toxic by-products produced during the process.

Pyrolysis of all types of thermoplastics has been published in the literature, with exception of PVC because it can cause corrosion in the system due to the liberation of chloride in the pyrolysis reaction.

In this research, a pyrolysis system has been designed using a mixture of polyolefins from the waste plastic management, highly contaminated, which cannot be processed by conventional mechanical recycling. It is a laboratory scale system with continuous feed that can be adapted to consume pyrolysis gas for the heating component, increasing the efficiency of the system and decreasing the dependence of external source of energy.

2 Materials and Method

2.1 Design of the Pyrolysis Prototype

The material to be consider for the pyrolysis is a mixture of polyolefins, mainly polyethylene and polypropylene from the local waste plastic operator. It is received has a mixture of flakes, highly contaminated, and they were rejected for conventional mechanical recycling. Regarding the pyrolysis prototype, being an experimental equipment, it is intended to be capable of adjusting to different control parameters and adapting according to the fractions of pyrolytic oils that may be produced. A literature review [3] was conducted to survey the conditions and working ranges for the pyrolysis of polyolefin mixtures.

The prototype conceptual design should consider the following parameters that can influence the process of pyrolysis [3]:

- Temperature;
- Rate of heating;
- Residence time in the reactor;
- Quantity of material and size;
- Density and moisture content;
- Catalyst and type of contact with the material;

– Pressure.

The temperature in pyrolysis is decisive for the reaction to take place and to form the desired products. Therefore, for the reaction to occur, the particles are subjected to a temperature, called the pyrolysis temperature and it affects the yield of the pyrolysis products. At low temperature, a higher amount of carbonization occurs, while at high temperature the gasification yield is higher. In the case of plastics, it was found in the literature that the optimum temperature range is 450 and 500 °C. Gases are formed in greater quantities at higher temperature [2, 4, 5]. The presence of catalyst can help to reduce the temperature.

The effect of the heating rate, by itself, does not define the pyrolysis products, but this parameter is of great importance, as a fast heating up to the pyrolysis temperature may generate more volatile gases, consequently more liquid (depending on the final temperature) and slower heating will generate more carbonization [4]. Depending on the heating rate used, it can be defined three main types of pyrolysis processes: slow pyrolysis, fast pyrolysis, and flash pyrolysis. In literature can be found different heating rates for biomass and plastics. For biomass, the heating rate of slow pyrolysis would be between 0,1 a 1 ºC/s, fast pyrolysis between 10 and 200 ºC/s and for flash pyrolysis higher than 1000 ºC/s [6, 7]. For plastic, the literature refers to slow pyrolysis when the heating rate is from 10 up to 100 ºC/s or less, the heating rate for fast pyrolysis between 100 up to 10.000 ºC/s and flash pyrolysis higher than 10.000 ºC/s [8, 9]. Since the main goal is to produce liquids, in the range of fast pyrolysis, it is important to understand the meaning of the heating rate in practice, for convenience to control this parameter in the design of the equipment. Hereby, the heating rate is managed controlling the heating load to the reactor at given feeding rate. It is the rate of temperature increasing per unit time during the contacting time, as soon the plastic enters the reactor [8].

In the pyrolysis process, one of the most important variables is the residence time inside the reactor of the volatile compounds generated, during which secondary and tertiary reactions occur, which alter the distribution of products generated in the first stage of the decomposition of the polymer [2]. Thus, some studies on the influence of residence time on the products generated by the pyrolysis of plastics concluded that the increase in residence time causes an increase in the proportion of gases to the detriment of liquids [2].

The amount of sample and particle size are factors that fundamentally affect the transfer of matter and heat transfer in the reactor, since large particles do not heat up as quickly as small ones. The smaller the particle size, the lower the amount of solid product obtained, as the production of gases and liquids increases.

With a high density sample to be pyrolyzed, the products will be captured as tars, leading to greater degradation and therefore a decrease in the production of the solid fraction and heavy hydrocarbons. In addition, if the sample has a high moisture content, part of the heat provided to decompose this material is consumed in the drying of the sample, and its decomposition occurs at a lower temperature than the nominal one, favoring the formation of the solid and liquid fraction [2].

The heat is one of the essential parameters to overcome the barriers of thermal decomposition of the material to be pyrolyzed, where this heat is controlled through temperature. However, to produce sufficient heat, it will be necessary to consume large amounts of energy (highly endothermic). To reduce energy consumption, it is necessary to lower the activation energy of the pyrolysis reactions and to use efficient heating systems. The use of induction heating will be tested. It offers numerous advantages, over 98% more efficient at converting electricity to heat, 30% energy savings, safer operation since it eliminates the need for open flame and heating mediums, does not produce dust, odor, noise and hazardous gases and digital control systems ensures accurate temperature control, offering an intelligent operation [10]. To reduce the consumptions of energy for the induction system, and consequently, the working temperature, can be used catalysts that reduce the activation energy, speeding up the rate of reaction [11]. The catalyst must have [11]: a presence of Lewis and Brønsted acid sites, since the combination of these sites allows for different reaction pathways in the polymer degradation; physical properties, such as high surface area, pore size, and pore volume. Hernández et al., 2006 [12] tested the effect of residence time in HDPE in the presence and absence of the zeolite HZSM-5 with a fluidized bed reactor. The effect of catalyst was more evident at low residence times and increased the yield in the range of 15–200 times the thermal value. To promote the contact between the catalyst and the materials to be pyrolyzed, it is also necessary to use more efficient reactors. According to the literature, fluidized bed reactors are expected to be the most efficient in promoting contact between the catalyst and the material to be pyrolyzed combined with solid catalyst, such as nanocrystalline zeolite (HZSM-5, HUSY, Hβ, HMOR, …), fluid catalyst cracking (a mixture of zeolite, acid matrix and binder) and silica-alumina [11].

The operating pressure is an essential parameter for the mechanical design of the reactor, since this parameter is used to establish a maximum value to be supported by the reactor, as well as by each of the elements used for pyrolysis. The effect of pressure on the pyrolysis of plastic occurs with pressures in the range of 0.1–0.8 MPa where pressure has the greatest impact on the residence time at a lower temperature. However, as temperature increases ($T > 430$ °C), the effect of pressure on residence time is less evident [13].

2.2 Experimental Setup

The development of the experimental setup was based on the literature review, considering the main goal to produce liquids by fast pyrolysis with catalyst of a mixture of waste plastic, polyolefins, mainly polyethylene and propylene. The reactor operates in continuous mode in a fluidized bed from 400 up to 500 ºC with a feeder/pre-heating system and three condensers. The Fig. 1 presents the pyrolysis system designed with the use of CAD, namely SolidWorks.

The plastic waste mixture is previously cut into small pieces of less than 2 mm and it is introduced in the feeder. The worm screw transfers the material into the reactor. During the transfer, the material is degassed and pre-heated at 105 ºC for drying and reduce the oxygen content. In the reactor, previously loaded with catalyst in a fluidized bed with nitrogen, the material is pyrolyzed at 450 ºC during 0.035 up to 3.5 s (fast pyrolysis), controlled by the worm screw speed and nitrogen flow of the fluidized bed.

The pyrolytic vapor flows by the condensers, helical-coil heat exchanger type [14] cooled with water. The temperature of the condensers is controlled with cold water in counter current and the condensers were dimensioned by the methodology described in

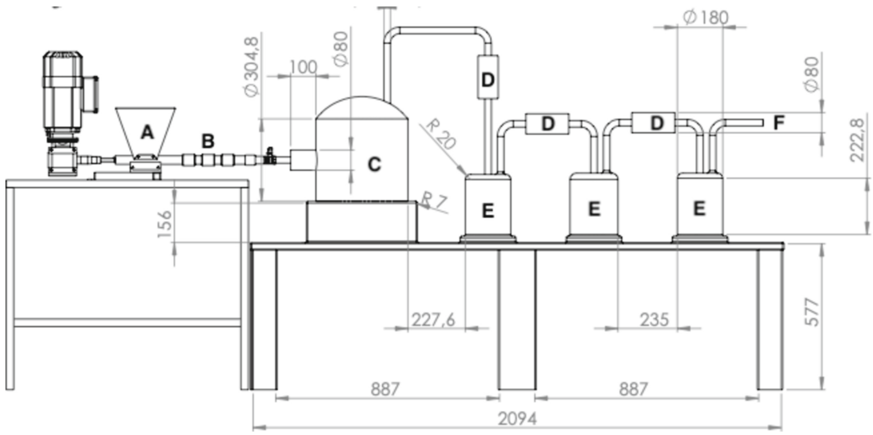

Fig. 1. Pyrolysis system: A – feeder; B – worm screw with pre-heating and degassing; C – reactor; D – condensers; E – storage tank; F – gas venting (non-condensing material).

the literature [15] and simulated with DWSIM [16]. The use of three condensers and three storages tanks allow to separate different substance based on their boiling temperature group. For the first storage tank will be selected the condensation of substances with the boiling point higher than 325 ºC (> C18), in the range of motor oil and wax. In the second storage tank, substances with the boiling point between 200 and 325 ºC (C11 up to C21) in the range of diesel (C12-C20) and kerosene (C6-C16). For the third storage tank, substances with the boiling point between 25 ºC and 200 ºC, (C5 up to C11) in the range of gasoline (C4-C12), jet fuel (C5-C14), kerosene (C6-C16) and petroleum (C14-C12). The gas, such as, methane, ethane, propane, butane, hydrogen, nitrogen, and others are vented or can be captured to be burned to produce heat to the reactor (not considered in the present study).

3 Results and Discussion

3.1 Design of the Worm Screw

According to the equations presented in previous work [3], the worm screw and the electric motor were dimensioned. The Table 1 presents the main results, corresponding to the parameters represented in the Fig. 2. The induction resistors (H1, H2, H3 and H4) will be used for the preheating of the material along its length, each with their respective control, allowing an improved control of heating. According to Savgorodny [17] and the project of Gómez and Bedoya (2007) [18], the diameter of the worm screw could be similar to the pitch, $D = t_{teo}$. The helix angle of the helical channel increases from its minimum value, in the outer diameter, to its maximum, in the core of the shell. This angle is the channel helix angle, φ [3, 18]. The length, L, is determined based on the diameter, D, and the most common L/D for plastics is about 20 to 24 [3]. Usually, for plastics, the diameter of the screw is between 9 and 500 mm [3]. With the diameter of 25.5 mm [3], the length would be 620 mm. The main shaft has regular channel helix angle since the different zones of feed, compression and metering were not dimensioned.

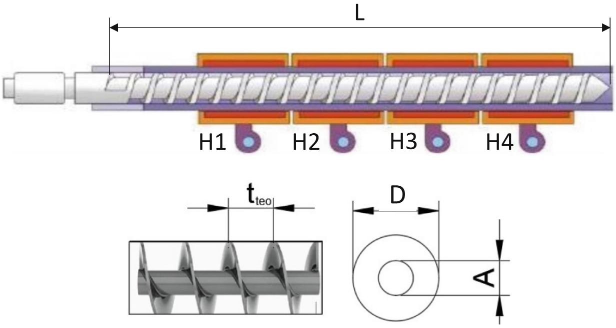

Fig. 2. Representation of the parameters of the worm screw [18].

Table 1. Construction parameters of the worm screw [3].

Parameter		Result	Units
Length	L	620	mm
Diameter	D	25.5	mm
Shaft diameter	A	16.1	mm
Pitch	t_{teo}	25.5	mm
Channel helix angle	φ	17.66	
Number of channels	m	1	
Crest width	e	3.06	mm
Fillet thickness	δ	0.05	mm
Fillets		24.3	

The Table 2 presents the parameters related with the production, with the use of the worm screw, including the power of the electricidal engine to move the worm screw. It is expected a maximum capacity to introduce into the reactor of about 24.43 kg/h and a maximum pressure in the worm screw of about 545 MPa at 112 rpm. The best material for the construction of the worm screw was done based on results presented in Table 2, material selection charts from Cambridge University [19], temperature interval of 97 up to 500 ºC, and price. The selected material for the feeder, including the worm screw, was the carbon steel.

The reactor has a capacity of 22 L to receive the expansion volume of the solid plastic into pyrolytic vapors and gases, estimated from the reception of 23.76 g per 3.5 s time residence, at 6.79 g/s, expanding to about 24.8 L per 3.5 s time residence (assuming no carbonization). The volume of vapors and gases were estimated by Peng-Robinson equation of state, modeled by process simulation in DWSIM software [16].

The condensers were modeled and simulated in DWSIM, considering helical-coil heat exchangers [15] and advanced Peng-Robinson equation of state [16] (see Fig. 3). Assuming carbon steel for tubing of 25 mm (internal diameter), the three condensers

Table 2. Production data of the worm screw [3].

Parameter		Result	Units
Spindle revolutions	η	112	rpm
Compression relation	R_{Com}	3.33	
Power electric motor	N	1.32	kW
Volumetric flow	Q	429	cm^3/min
Drag flow or friction	α	3.84×10^3	mm^3
Pressure flow	β	0.090	mm^3
Filtration flow	γ	1.43×10^{-5}	mm^3
Head constant	k	16.73	mm^3
Production	prod	24.43	kg/h

were estimated with 5 helical-coil, respectively, to remove the heat from the pyrolytic vapors. The number of helical-coil were fixed to simplify their production. From the first condenser is expected a temperature variation of 25 up to 80 ºC of the water cooling at 50 kg/h, in the second condenser is expected a variation from 25 up to 65 ºC at 50 kg/h and in the final condenser, from 25 up to 32 ºC at 50 kg/h.

The 3D model was modeled with SolidWorks, control system modelled in CADe SIMU and particle simulation with FloXpress. The simulation with FloXpress at 500 ºC and 0.8 MPa shows the circulation of the particles in the system from the reactor through the condensers and storage tanks, Fig. 4.

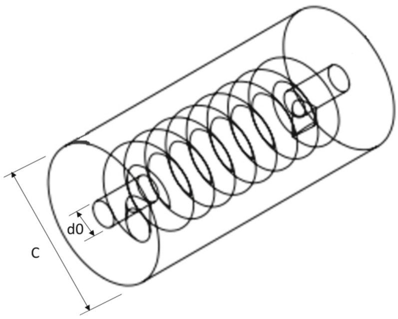

Fig. 3. Condensers, helical-coil heat exchangers. C is the width of the condenser and d0 is the external diameter of helical-coil tube, where C is 260 mm and d0 is 30 mm.

The construction of a plastic pyrolysis reactor at the laboratory level represents a crucial step in the pursuit of sustainable solutions for plastic waste treatment. This reactor offers the necessary flexibility to adjust a variety of control parameters, allowing for experimentation and optimization of the pyrolysis process. Additionally, the ability to measure and control energy consumption is essential to ensure energy efficiency and reduce the environmental and economic impact of plastic pyrolysis.

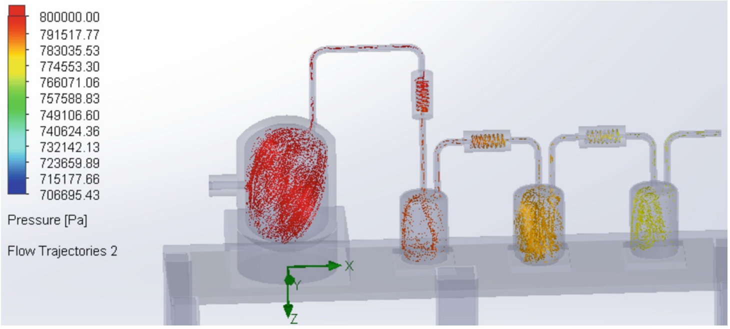

Fig. 4. FloXpress simulation.

An essential aspect of this study is the investigation of different catalysts and the exploration of mixtures of polyolefins with other types of plastics. This approach aims to maximize process efficiency and find solutions that can be applied on an industrial scale.

Optimization of plastic pyrolysis is crucial to improving energy consumption and reducing its environmental and economic impact. By converting plastic waste into various types of fuels, we can significantly reduce the amount of plastic that is disposed of in landfills or incinerated. This not only reduces the direct environmental impacts of these disposal methods but also contributes to mitigating greenhouse gas emissions.

The implementation of this technological solution at an industrial level promises a significant reduction in emissions to the atmosphere. Furthermore, the reduction of solid emissions, which traditionally end up in landfills, represents an important advancement in the sustainable management of plastic waste. Research and development of plastic pyrolysis represent a promising approach to addressing the global challenge of plastic waste, providing significant environmental, economic, and social benefits.

4 Conclusion

One of the advantages of using plastics is their recyclability. Unfortunately, conventional mechanical recycling, even with hot water, is incapable of efficiently recycling highly contaminated plastics. Among advanced recycling technologies, pyrolysis is expected to contribute significantly to the recycling of highly contaminated plastics.

In this study, we examined and designed a pyrolysis system for plastics with the primary objective of transforming plastics into pyrolytic oil. The system comprises a material feeding, and transport system facilitated by a hopper and a worm screw coupled with an induction heater system. During the design of each element in the process, it was essential to ascertain the types of materials they could withstand. We opted for carbon steel due to its ability to endure high temperatures, torsion, and stress.

In the design of the screw elements, various factors were considered to ensure the proper operation and material transport through the screw, maximizing its efficiency. Calculations indicated a total production of 24.4 kg/h at the screw exit, which would be conveyed to the reactor.

The reactor, designed for the pyrolysis process of plastics, features a steel cylinder with two shells that hermetically seal the reactor. The induction heaters provide the necessary heat. At the reactor's outlet, a pipeline transport system conveys the material to multiple condensers and storage tanks. In the condensers, temperature changes convert vapor into a liquid state. This condensation process, consisting of helical-coils for extended transformation time, is repeated twice to obtain a more refined oil.

Computational modeling allowed us to visually assess the fluid's pressure behavior as it circulated through the ducts until its exit. The electrical motor power yielded a power of 1.31 kW. Consequently, a 2 hp motor, selected from motor selection tables, was chosen to operate at 112 rpm in conjunction with a speed reduction system for optimal functionality.

Using the CADe SIMU software, the electrical control components of the motor, variator, and heating system were designed to optimize the pyrolysis process, efficiently utilizing resources in the transformation of plastics into pyrolytic oil. The presented system for transforming plastics into pyrolytic oil aims to elevate production levels and enhance the utilization of plastics.

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Unveiling the Sustainable Layers of Barcelona's Metropolitan Public Sphere

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Abstract. The evolution of Barcelona's metropolitan public space network represents a dynamic and multifaceted transformation, unfolding across various temporal and spatial dimensions. This process, delineated by scholars such as Solà-Morales (2011) and Torres i Capell (1999), is characterized by a series of interventions spanning three distinct layers. Firstly, there's the rejuvenation of public spaces within local urban fabrics across diverse municipalities in the metropolitan area. Secondly, attention is drawn to initiatives revolving around blue-green infrastructures. Lastly, emphasis is placed on projects and interventions addressing metropolitan roads and mobility concerns. Through these concerted efforts, a cohesive metropolitan public space is emerging, playing a pivotal role in enhancing environmental sustainability while imbuing urban areas with vital qualities such as accessibility, vibrancy, and aesthetic appeal amidst the complexities of the metropolitan landscape.

Keywords: local urban fabrics · blue-green infrastructures · mobility infrastructures

1 Introduction

When contemplating Barcelona, one cannot overlook its vibrant public spaces, which have become synonymous with the city's urban identity (Martí, 2004). Beginning in the early 1980s, the city embarked on a journey of public space renewal, a hallmark of its urbanism that has continued to evolve over the decades (Àrea Metropolitana de Barcelona, 2004, 2006, 2010, 2012, 2018, 2019a, 2019b, 2022) and has significantly influenced urban development across Catalonia (Bento, 2021).

As time progressed, the metropolitan scale emerged as a key catalyst in this transformative process (Parcerisa, 2014). Amidst the rejuvenation of local urban fabrics, a plethora of interventions with distinct metropolitan characteristics emerged, drawing

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attention to the interconnectedness and unique challenges of the metropolitan landscape, such as discontinuities and interstices.

Examples abound, from blue infrastructures like waterfronts and hydrographic networks to agricultural lands and peri-urban forests, all serving as quintessential metropolitan spaces. These areas, alongside transport infrastructures facilitating territorial connectivity, underscore the evolving relationship between public space and environmental sustainability.

In response to the imperative of climate change, concepts such as green infrastructure, ecosystem services, and nature-based solutions have reshaped public space dynamics. From seafront designs accommodating rising sea levels to the promotion of agricultural areas for both food production and fire prevention (Morán, 2020), the management of peri-urban forests, and the fostering of biodiversity conservation, these initiatives underscore a holistic approach to urban ecology.

Furthermore, efforts to promote sustainable mobility have left an indelible mark on public space design. Formerly segregated road infrastructures have transformed into vibrant metropolitan avenues, fostering social interaction, while the proliferation of cycle paths enhances accessibility to vast open spaces like seafronts and agricultural lands, thereby redefining the metropolitan landscape on a human scale.

This chapter delves into the intricacies of Barcelona's metropolitan public space, tracing the trends that have shaped its evolution in tandem with ecological and mobility paradigms. From innovative landscaping techniques that embrace nature's dynamism to a keen consideration of citizen perception in territorial design, Barcelona's public spaces epitomize a fusion of tradition and innovation in urban planning.

2 Revitalization of Urban Public Spaces in Local Metropolitan Areas

In recent decades, the Barcelona Metropolitan Area authority (BMA), in collaboration with metropolitan municipalities, has been a driving force behind the transformation and enhancement of the metropolitan public space network. Over 180 public space operations have been undertaken, with 40 specifically targeting local urban fabrics. While it's impractical to delve into each case here, we'll spotlight three instances, each demonstrating a metropolitan impact extending beyond their local boundaries.

Firstly, the Plaça Can Fradera in Badalona exemplifies a significant civic-green space in a major town of 223,000 inhabitants. Designed by architects JornetLlopPastor and completed in 2011, this 3-hectare Plaza-Park serves as a pivotal urban node, connecting various metropolitan spaces. Situated within the Badalona "Central Island," it embodies diverse urban values, aiming for unity while offering a range of distinct spaces, fulfilling both metropolitan gateway aspirations and the need for a central park within Badalona (Llop & Ruiz-Apilánez, 2021).

Next, the reurbanization of the streets in the historic center of Castellbisbal (population 13,000), designed in March 2017 by Cristina Sáez (BMA) and a collaborative team, transforms existing streets into a pedestrian-friendly zone. Through a unified platform accommodating both pedestrians and resident vehicles at low speeds, the redesign creates tiered spaces with seating areas and greenery, fostering quality leisure spaces within the urban fabric.

Lastly, the urban spaces of the Ciutat Cooperativa neighborhood in Sant Boi de Llobregat (population 83,000), designed by the AR47 team in 2016, merit attention. This project serves as a notable example of a peripheral settlement interfacing with hydrographic open spaces at the metropolitan level. Focused on enhancing accessibility and connectivity within the neighborhood, the proposal introduces a central pedestrian axis linking key amenities such as the market and library, thus organizing the residential spaces and fostering community interaction. Positioned adjacent to the Llobregat river valley and in close proximity to the cultural heritage of Colònia Güell, this neighborhood's strategic location offers unique opportunities for transformation and integration into the broader urban fabric.

3 Public Spaces Connected to Blue-Green Infrastructures

In the past few years, the BMA has been proactively initiating projects involving blue infrastructure to elevate sustainability, resilience, and the overall well-being of its inhabitants. Blue infrastructure encompasses both natural and man-made water systems, offering a myriad of advantages such as adaptation to rising sea levels, flood control, water purification, and recreational amenities. Additionally, a key focus of BMA's blue infrastructure efforts lies in the restoration of rivers and streams. Recognizing the significance of reclaiming and rejuvenating water bodies that were previously heavily polluted and degraded, the city has embarked on efforts to revitalize these vital natural resources.

3.1 Enhancement of Coastal Areas and Watercourse Interventions

The initiative at Gavà Beach is centered on finding a harmonious blend between tourism and environmental preservation. Administrative efforts have been directed towards safeguarding the fragile coastal ecosystem, ensuring the conservation of indigenous flora and fauna while simultaneously establishing pathways and recreational amenities for beach enthusiasts. Notably, Gavà Beach witnessed the inaugural dune system restoration project in the Barcelona metropolitan region. The infusion of artistic installations and outdoor recreational areas has metamorphosed Gavà Beach into a lively nucleus for cultural gatherings and communal activities, nurturing a sense of community among residents and fostering social unity.

Spanning the western expanse of the BMA, the Llobregat River stands as a vital watercourse for Barcelona. This expansive natural corridor is geographically separated from adjacent historical settlements by infrastructural corridors, comprising highways and railways. The restoration of the Llobregat Valley commenced in the early 1990s, guided by a dual-pronged approach.

Initially, efforts were concentrated on enhancing the ecological integrity of the valley. Measures were implemented to address pollution, alongside the creation of artificial meanders and wetlands. These wetlands play a pivotal role in water filtration, flood mitigation, and habitat preservation for diverse flora and fauna. Noteworthy is the Llobregat Delta Park, situated at the river's mouth, which has been augmented with biodiverse wetlands, serving as a sanctuary for migratory birds and acting as a natural buffer against coastal erosion. These metropolitan wetlands not only deliver ecological advantages but also offer inviting recreational spaces for residents seeking to immerse themselves in nature within urban environs.

The secondary aspect of the hydrographic system restoration strategy has focused on enhancing accessibility to hitherto inaccessible spaces. A network of blue routes (pedestrian and cycling paths along rivers and streams) is under development. For instance, along the Llobregat, two cycling paths now extend approximately 30 km each from Martorell to the river's mouth. Overcoming infrastructural barriers, such as pedestrian tunnels and bridges (e.g., in Sant Boi de Llobregat by Battleiroig, 2007–2015), facilitates connectivity between historical towns and these soft arteries. Once accessible, these open spaces offer enticing amenities such as natural areas, birdwatching spots, and observation towers.

3.2 Collserola: Barcelona's Metropolitan Central Park

Blue infrastructure forms a crucial component of the broader concept of green infrastructure, which encompasses a network of natural and semi-natural spaces strategically designed to deliver ecosystem services, including environmental and social benefits to the human community.

Beyond the coastlines and river systems, the BMA has undertaken significant efforts in recent years to implement green infrastructure projects, with the development of metropolitan parks emerging as a pivotal focus area.

The Central Park of Metropolitan Barcelona finds its embodiment in the Collserola mountain range. Spanning approximately 11,000 hectares, with over 8,000 hectares designated as a protected natural park, it offers boundless opportunities for outdoor activities and leisure.

In 2011, the Barcelona City Council initiated the Collserola Gates competition. The objective was to enhance access to the Collserola mountain from the city, envisioning it as the green lungs of the urban conurbation. With Barcelona's orientation towards the sea in the 1980s, it was deemed crucial to turn attention towards the mountains, historically serving as its natural boundary, further solidified with the construction of the Upper Ring Road for the 1992 Olympics. The aim was to reorganize the urban peripheries of the park and establish ecological connections in terms of biodiversity while enhancing accessibility for citizens to the network of pedestrian paths within the natural park. Sixteen areas, referred to as "gates," were delineated to be transformed into green corridors equipped with public amenities.

While many ideas from the competition remain unrealized, progress is underway for the completion of the Passeig de les Aigües project. The Water Promenade, spanning over 20 km, offers a flat path ideal for walking or biking, tracing the mountain's contours and providing breathtaking views of central Barcelona.

In 2020, the new Plan for the Natural Park of Collserola was approved, focusing on a vision from the perspective of the natural area rather than the surrounding settlements. The plan addresses human pressures resulting from increased outdoor activities by proposing "calm islands," areas within the park with enhanced protection to preserve their natural ecosystems. Recreational activities are encouraged along the park's edges, with designated nodes of amenities, while regulations governing recreational uses within the park's network of paths are stricter. Additionally, existing agricultural and livestock activities are maintained, with new ones introduced where feasible, particularly in the interfaces between the forest and urban settlements, to mitigate and manage fire risks effectively.

3.3 Urban Farming: Advancing Agroforestry Patterns in the Metropolitan Landscape

Another notable endeavor within BMA's green infrastructure framework involves the advancement of metropolitan agriculture. The Greater Barcelona region encompasses significant agricultural expanses within its boundaries. Shielded from the encroachment of urban sprawl, these areas offer the metropolis valuable access to locally sourced food, foster biodiversity, and preserve rural landscapes. The Agricultural Park of the Llobregat Delta stands as the primary expanse, while others persist in Vallès, situated north of the coastal range. Protection of metropolitan agricultural lands has been in place since the 1990s, with plans designed to integrate three key facets: primary production, ecological enhancement of the environment, and recreational activities.

In recent times, BMA has taken further strides by embarking on substantial endeavors to implement agroforestry mosaic projects (e.g., www.agroforadapt.eu). Agroforestry represents a land management approach that integrates tree cultivation with agricultural crops or livestock. This strategy not only bolsters agricultural resilience to climate change, particularly amidst escalating droughts in a Mediterranean setting but also amplifies the manifold benefits associated with sustaining agriculture within urban environments.

3.4 Enhancing Urban Environments: Sustainable Urban Drainage Systems (SUDS), Blue Green Infrastructure (BGI), and Urban Gardens

Incorporating sustainable urban drainage systems (SuDS) stands as a key component of blue-green infrastructure initiatives within the BMA. Barcelona has adopted a range of SuDS techniques, such as permeable pavements (e.g., Cristobal de Moura green street) and rain gardens (implemented in select superblocks in Poble Nou), aimed at mitigating the impacts of urbanization on the water cycle.

Simultaneously, the integration of green roofs and walls constitutes a notable feature of green infrastructure endeavors within the BMA. These installations offer manifold benefits, including enhanced energy efficiency, stormwater management, and improved air quality. Barcelona's municipal authorities have actively encouraged the adoption of green roofs and walls in both new construction projects and the retrofitting of existing buildings, as evidenced by the biannual Cobertes Verdes competition.

Furthermore, Barcelona has underscored the significance of cultivating food within urban areas to bolster food security and foster community engagement, exemplified by initiatives like the Horts Urbans network.

4 Public Spaces Shaped by Metropolitan Mobility Infrastructures

The transformation of the mobility system presents another significant path for the creation of metropolitan public spaces, involving the repurposing of rigid roads previously dedicated solely to car traffic. These road infrastructures, integral to the metropolitan landscape, feature lanes bustling with vehicles alongside vacant stretches, roundabouts, railway tracks, and complex concrete structures at varying elevations. However, these infrastructures also encroach upon natural ecosystems, fragmenting the landscape and hindering access to metropolitan fields and forests.

Within these spaces lies an opportunity to repurpose fabrics and infrastructures to integrate the metropolis. Urban dynamics characteristic of the city center can be extended to these areas in innovative ways. The "Nusos i Cruïlles" competition, initiated by the BMA authority in 2020, showcases diverse approaches to repurposing road junctions and highways to accommodate alternative forms of mobility. Proposals include incorporating bus stops on motorways, creating pedestrian pathways amidst highway chaos, and establishing new civic squares and streets within this infrastructural landscape.

This competition aims to contemplate the implementation of the urban and social structure outlined in the Metropolitan Urban Master Plan (PDUM), currently under approval. This structure prioritizes proximity between different land uses, sustainable mobility, and urban continuity across municipalities. Presently, many metropolitan roads act as barriers that didn't exist decades ago, segregating urban fabrics and fragmenting natural ecosystems. The envisioned structure seeks to address these issues, emphasizing a system of diverse mobility channels, including metropolitan avenues, streets, and paths.

The network of metropolitan avenues and streets serves as the backbone of this structure, designed to prioritize pedestrians, connect neighborhoods, and facilitate various modes of sustainable transportation. An ongoing example of this redesign is the transformation of the historical road C-245 along the municipalities bordering the Llobregat Delta, and the planned conversion of the C-31 highway into a metropolitan avenue, integrating public transport, bike lanes, and pedestrian-friendly spaces.

Metropolitan paths, on the other hand, play a crucial role in facilitating access from urban areas to agroforestry spaces while organizing their use. Often tracing historic routes, these paths serve as links between nature, heritage, and urban areas, promoting soft mobility modes such as walking, running, and cycling, as exemplified along the Llobregat river.

5 Findings

In 2023, the initial endorsement of the Metropolitan Urban Master Plan (PDUM) marked a significant milestone. The PDUM serves as a blueprint, outlining regulatory frameworks and directives for Barcelona's metropolitan area up to 2050, with a primary focus on enhancing the natural assets of the region, fostering active and sustainable mobility, and elevating overall quality of life.

Regarding metropolitan public space, these PDUM objectives align with the three layers addressed in this chapter: enhancing urban public spaces to enrich urban fabric quality of life, implementing blue-green infrastructure to amplify natural values, and developing transport infrastructures to facilitate sustainable mobility. These layers are intricately interwoven, with interventions complementing one another to form a cohesive network of public spaces.

Beyond efforts to restore ecological integrity and sustain productivity in terms of food and timber, the network of metropolitan walkable and bikeable paths introduces a

Fig. 1. The new metropolitan "Passeig de Gràcia", Barcelona (Pedro Bento, 2023)

newfound accessibility to expansive open spaces previously out of reach. These paths serve both leisure activities and daily commuting, effectively structuring the metropolis at a human scale and enhancing its legibility.

Simultaneously, metropolitan avenues serve as conduits connecting traditional urban public spaces within neighborhoods to emerging public spaces within the domain of transport infrastructures. Along thoroughfares and expressways, particularly at their intersections, a distinct metropolitan landscape takes shape (See Fig. 1: The new metropolitan "Passeig de Gràcia"). This landscape offers urban characteristics - accessibility, vibrant activity, harmonious integration of elements, aesthetic appeal - within a context characterized by the discontinuities and lack of order of a sprawling cityscape (Sabate, 2019). The aspiration to establish a system of metropolitan public spaces is nearing fruition, creating locales with unique identities while upholding the qualities previously achieved in urban settings.

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Cultural Agroecosystem Services Framework (Agro-CES): A Tool to Support Agricultural Sustainability Assessment

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Abstract. Agroecosystems (AE) are complex socioecological systems that can provide several cultural ecosystem services (CES), such as traditional knowledge, recreation, or a sense of place, that are often overlooked. However, CES are crucial for people's physical and mental well-being and need to be recognised. While there has been an increase in publications on this topic, a framework that considers a holistic set of indicators covering all CES classes applicable to AE is still missing. This work aimed to develop a framework for the study area of the CULTIVAR research project (https://icultivar.pt) in east central Portugal, which has a diverse agricultural landscape with outstanding cultural and natural values that deliver a multitude of CES. Through literature review, data search and expert opinion, we identified 20 potential proxy indicators for agroecosystems CES, considering the Common International Classification of Ecosystem Services classification system (CICES). Each indicator was scored based on the time required to collect data, data analysis complexity, relevance for the project goals, and capacity to map the indicator. After this step, we prioritised and selected 6 CES to be assessed for the Cultivar study area.

Keywords: Agroecosystems · CES · Indicators · Portugal

1 Introduction

Ecosystem services (ES) encompass the natural components that directly contribute to improving or sustaining human well-being [1, 2] and have been increasingly advocated as a tool to support decision-making related to the management and maintenance of natural resources [3–5]. The significance of this endeavour has been acknowledged by the European Biodiversity Strategy 2020, which urges all member states to conduct mapping and assessments of ecosystems and their associated services as pivotal tools for

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biodiversity conservation and ES preservation. Consequently, a standardised reference framework named MAES (Mapping and Assessment on Ecosystems and their Services) has been established to facilitate a harmonised evaluation of ES throughout Europe, built upon the globally recognised Common International Classification of Ecosystem Services system (CICES), that offers a relatively high level of detail hierarchical structure [6, 7]. According to CICES, ES are classified into three categories: (1) Provisioning services, which are the material and energetic outputs from ecosystems from which goods and products are derived; (2) The Regulation and Maintenance services category includes how ecosystems can mediate the environment in which people live or depend in some way and benefit from them regarding their health or security, for example; and (3) Cultural services that includes all the non-material characteristics of ecosystems that contribute to, or are essential for people's mental or intellectual well-being [7].

Previous studies have established a correlation between landscape biodiversity, ES and human well-being [8–10]. Agroecosystems (AE) are a prime example of this concept, showcasing intricate socioecological systems capable of delivering numerous ES. These services encompass not only food production but also various regulation and maintenance ES such as pollination, habitat preservation or carbon sequestration [11]. It also includes cultural ecosystem services (CES), offering a myriad of benefits such as centuries of traditional knowledge and practices or recreational spaces amidst natural beauty [12, 13]. Despite their significance, the CES of AE are frequently undervalued [14]. Nonetheless, it is crucial to realise their importance in promoting physical and mental wellness. CES play an essential role in shaping local cultures, strengthening community bonds, and preserving cultural heritage. They foster a sense of belonging and appreciation for one's environment and history and should be appreciated and valued.

Preserving CES is thus vital to maintaining the global community's ecological, social and cultural integrity. In this context, it is essential to define a standardised framework [17, 18] that identifies CES' proxy indicators that ensure that assessment outcomes are directly relevant to human welfare [19]. Furthermore, they present compelling reasons for the conservation of ecosystems, and their explicit characterisation is a challenge due to their intangibility and difficulty in being measurable. While there has been an increase in publications on this topic, a framework that considers a holistic set of indicators covering all CES classes applicable to agroecosystems still needs to be defined.

Evaluating CES based on indicators that capture agricultural landscapes' cultural significance is crucial to informing decision-making, engaging communities, preserving heritage, and promoting sustainable development. This work aimed to develop a CES framework for the integrated program CULTIVAR—Network for sustainable development and innovation in the agri-food sector (https://icultivar.pt/en/home_en/). It aims to support the assessment of agricultural ecosystems' non-material benefits and to value their contribution to people's physical and mental well-being, which goes far beyond their productive function.

2 Cultural AgroEcosystem Services Framework (Agro-CES) for CULTIVAR

2.1 Study Area

The Agro-CES framework was defined for the CULTIVAR project study area, which covers seven municipalities of the Beira Interior region in Central East Portugal (Sabugal, Belmonte, Covilhã, Fundão, Penamacor, Idanha-a-Nova and Castelo Branco). The area has about 19% farmland, 10% grassland and 6% agroforestry (Fig. 1). It has diverse agricultural landscape mosaics with outstanding cultural and natural values that deliver a wide range of CES that are not duly documented.

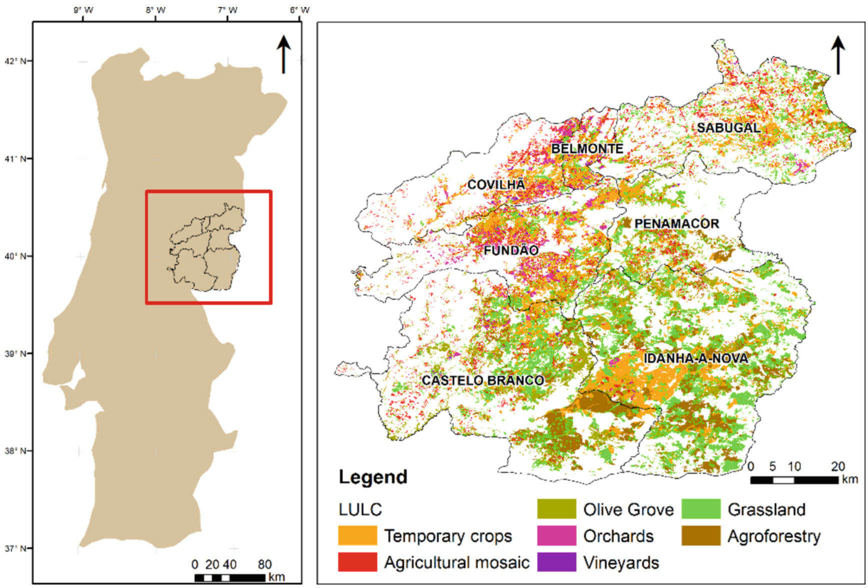

Fig. 1. Agricultural occupation in the Cultivar Study area based on the Portuguese Land Use Land Cover (LULC) (COS 2018).

2.2 Proxy Indicators List and Selection Procedure

The initial overview of potential CES indicators involved the following steps:

- Based on the literature review, for each CES class identified in CICES v5.1 [7], a list of potential proxy indicators (PI) that could be used for agroecosystem site-level assessment was built, and summarized (Table 1).
- Based on expert opinion (Appendix 1), each proxy indicator was scored using a 5-point Likert scale, considering the following criteria:

  – Time required to compile the data: from **1** (very time-consuming) to **5** (ready for use);

- Data analysis complexity: from **1** (very complex) to **5** (very simple);
- Relevance considering medium-long term goals: from **1** (very low relevance) to **5** (very relevant);
- Spatialised information, where 1 is not a spatial indicator, 2 and 3 were very broad locations (e.g., municipality/parish level), 4 more accurate locations and 5 concrete coordinates;

- The cost-effectiveness of each PI was evaluated based on the average value of the criteria mentioned above. The results are shown in Table 1 as the "final score". This information was used to select the PI to assess CES for the CULTIVAR study area.

Table 1. Proxy indicator list identified for each CICES class. Each one was scored based on cost-benefit from 1 to 5 (**1.** Very low**; 2.** Low**; 3.** Medium**; 4.** High; **5** very high). The underlining indicates those that were selected to be evaluated for the CULTIVAR study area.

CICES V5.1			**Proxy indicator (PI)**	**Final Score**
Division	**Group**	**Class**	**Proposed list**	
3.1 Presence-based interactions	**.1** Physical, experimental interaction	**.1** active/immersive interactions	<u>**PI.01** Recreation infrastructures in AE</u>	<u>**4**</u>
			PI.02 No. Agro-tourism farms	**3**
		.2 Passive/observational activities	<u>**PI.03** Citizen science data in AE</u>	<u>**5**</u>
			PI.04 No. of photographic records	**4**
	.2 Intellectual, representative interaction	**.1** Research in AE /trad. Knowl	**PI.05** No. Scientific papers on AE	**3**
			PI.06 No. Master/PhD thesis on AE	**2**

(*continued*)

2.3 CES Assessment and Mapping Methodology

According to the final score of each PI (Table 1), 6 indicators related to 6 CICES classes were selected and analysed under the Agro-CES framework, considering the methodology shown in Table 2. The spatial information was obtained from open data services

Table 1. (*continued*)

CICES V5.1			**Proxy indicator (PI)**	**Final Score**
Division	**Group**	**Class**	**Proposed list**	
		.2 Education about AE	**PI.07** No. Pedagogical farms	**3**
			PI.08 No AE education activities	**2**
		.3 AE people identify with history/culture	**PI.09** No. Agricultural / livestock fairs	**3**
			PI.10 No. Certified products/producers	**3**
			PI.11 Cultural landscapes	**5**
		.4 AE that enable aesthetic experiences	**PI.12** Agricultural songbook themes;	**2**
			PI.13 No. Painted murals related to AE	**2**
			PI.14 No. Literary landscape references	**3**
3.2 Interactions that require no presence	**.1** Spiritual, symbolic or other interaction	**.1** AE symbolic meaning	**PI.15** Coats of arms with AE motif;	**4**
		.2 AE elements sacred meaning	**PI.16** Religious festivities with an agricultural root	**2**
		.3 AE used for entertainment	**PI.17** No. Territorial documentary/ promotion movies	**2**
	.2 Other Non-use value	**.1** AE that should be conserved	**PI.18**% agriculture in Protected Areas;	**5**
			PI.19 Protected species dependent on the agricultural mosaic	**4**
		.2 AE for future generations	**PI.20** National agricultural reserve	**5**

(Appendix 2), and analysed considering a 1km grid system. For each cell, the number of PIs and/or the area occupied by each indicator was weighted by the area that AE represents in each cell. This resulted in all PI varying between 0–1.

Table 2. CES assessment and mapping methodology, considering the selected proxy indicators.

CICES	PI	Methodology
3.1.1.1	PI.01	A 500m buffer from all infrastructures that promote recreational activities in nature (e.g., certified hiking trails, viewpoints) was used to access the AE that could be visited/enjoyed from these infrastructures;
3.1.1.2	PI.03	All records from citizen science platforms related to biodiversity observations (e.g., birds, plants) that coincide with AE
3.1.2.3	PI.11	Cultural landscapes were based on 3 classes of Portuguese Land Use Land Cover (COS18): agricultural complex mosaics, agriculture with natural and semi-natural spaces and agroforestry areas
3.2.1.1	PI.15	All heraldic symbols with a relation to AE, (e.g., grapes), were grouped with their corresponding COS18 class to map their symbolic value in each parish coat of arms
3.2.2.1	PI.18	AE included in the National Protected Areas (PA) network (e.g., Serra da Malcata, Serra da Estrela, International Tagus River) were considered
3.2.2.2	PI.20	The Portuguese National Agricultural Reserve (NAR) was used as PI, since it is a territory management instrument that plays a fundamental role in preserving the soil resource and its allocation to agriculture

3 Results and Discussion

The obtained results for the 6 CES are presented in Fig. 2. The CES provision gradient varies between 0 and 1, with darker tones indicating greater provision of services. Cells which have AE but have not been verified for CES provision have no color, while grey cells represent areas without agricultural occupation, and thus no cultural services related to AE were expected from them. Regarding the CES linked to active or immersive physical experimental interaction (**CICES 3.1.1.1**), the **PI.01** relates the existing recreation infrastructures and its presence in agricultural landscapes. This CES has better coverage in the municipalities of Sabugal (except near the border), Fundão, Penamacor (both the areas closest to PA), the northern part of Idanha-a-Nova and the western part of Castelo Branco. The remaining areas are mainly connected by major pedestrian or car routes.

On the other hand, the **PI.03** connected to the passive or observational activities (**CICES 3.1.1.2**), which considers the number of biodiversity records from citizen science platforms (aggregated in GBIF) that were done in AE landscapes. The analysis shows that the most populated municipalities (Covilhã, Fundão, and Castelo Branco) tend to have more biodiversity records, even in agricultural areas.

As a proxy indicator (**PI.11**) for the agroecosystem elements that people identify with their history and culture (**CICES 3.1.2.3**), the COS18 classes most closely linked

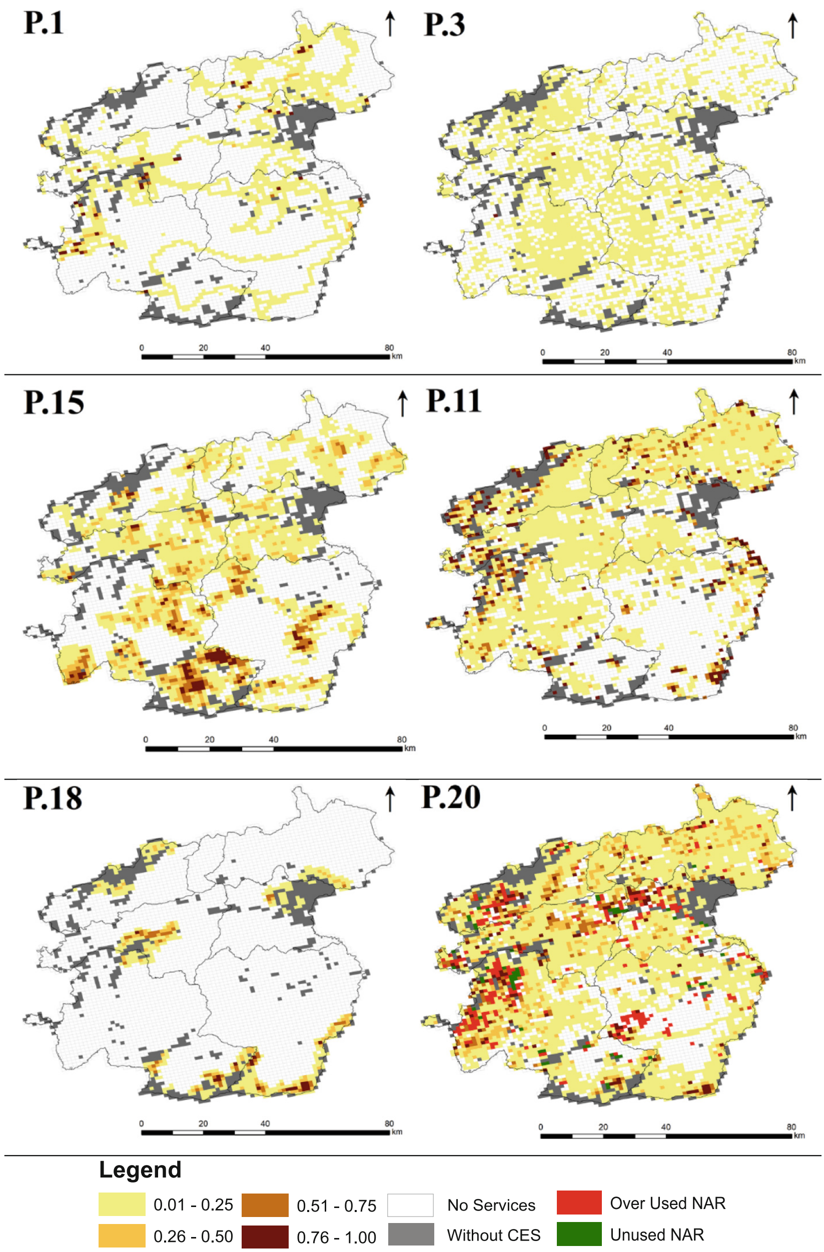

Fig.2. Distribution of the 6 CES assessed for the CULTIVAR study area.

to the cultural landscapes of agriculture in the region, including agricultural complex mosaics, agriculture with natural and semi-natural spaces, and agroforestry areas were used. The municipality of Idanha-a-Nova emerges as the area with the least cultural landscapes, perhaps because its agricultural aptitude allows for more intensive cultivation. Conversely, the more mountainous areas in the western part of the study area (Covilhã, Fundão, and northwest of Castelo Branco) and the Sabugal plateau tend to have higher values of these cultural landscapes. Additionally, the area bordering Spain in the Idanha-a-Nova municipality, probably due to its steeper slope towards the rivers, also has some cultural landscape hotspots.

Concerning the elements with symbolic meanings (**CICES 3.2.1.1**), and the relation between each parish coat of arms heraldic symbols and the agricultural COS18 classes (**PI.15**) it was noticed that they were particularly significant in Castelo Branco, and in some parishes of Fundão, Idanha-a-Nova, and Sabugal.

For the CES related to the non-use value, namely the elements that should be preserved due to their existence value (**CICES 3.2.2.1**), the **PI.18** considered the national network of protected areas. Even though these areas often have farming restrictions due to their main conservation goals, the study confirms that there are still some agricultural areas within these protected areas. These include the Tagus International Natural Park in the southern areas of Castelo Branco and Idanha-a-Nova, and the Protected Landscape of the Gardunha Mountains in Fundão. Agricultural areas are less significant in the Serra da Estrela Nature Park (Covilhã) and in the Serra da Malcata Nature Reserve (in the municipalities of Sabugal and Penamacor).

As for the features of AE that hold an optional or bequest value (**CICES 3.2.2.2**), the Portuguese network of the National Agricultural Reserve (NAR) can serve as a good proxy indicator (**PI.20**) for this CES. The NAR is a territorial management tool that aims to protect the soil resource and allocate it to agriculture for future generations. For this PI, we have added an additional class (in red) to represent the grids where the NAR area is greater than the area currently used for farming. These areas are mainly located in mountainous regions, some of which are forest plantations or the result of vegetation growth after agricultural abandonment.

Based on the analysis of those 6 ES services, Fig. 3 shows the number of confirmed cultural ecosystem services (CES) present in each cell. The areas with the highest provision of CES linked to AE are located in the area known as "Cova da Beira" region, which is situated towards the east of the municipalities of Fundão and Covilhã, in the municipality of Belmonte, and in the western part of the municipalities of Penamacor. In Sabugal, almost the entire area has several CES linked to the agricultural component, whereas in Idanha-a-Nova, the highest provision occurs in the border areas of the municipality. On the other hand, the areas with the lowest provision of cultural services linked to AE are situated in the Serra da Malcata Reserve, especially in the area within Penamacor municipality, and the western area of Covilhã, Fundão, and Castelo Branco municipalities.

4 Final Remarks

Agri-CES are widely distributed throughout the CULTIVAR territory, with some areas standing out. However, indicators have yet to be weighted to guarantee a clear and realistic vision regarding the most relevant areas for providing CES.

To effectively manage and conserve agricultural landscapes, it is crucial to have a nuanced understanding of the CES and their distribution patterns in the territory. By

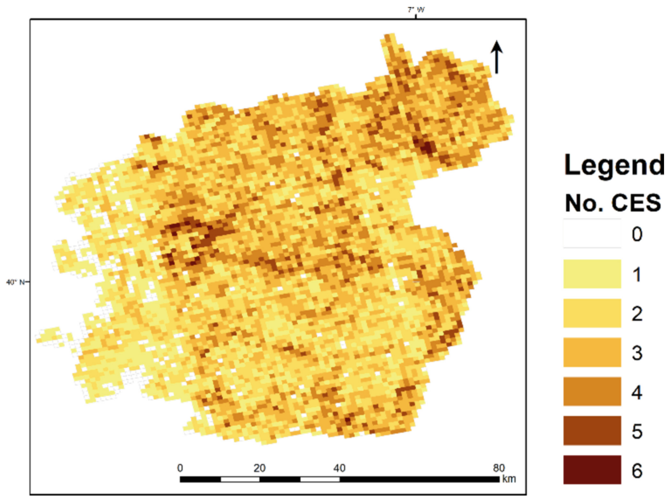

Fig.3. Number of ES counted in the study area Cultivar (accumulations of the 6 ES).

developing and using weighted indicators, stakeholders can gain a clearer and more realistic vision of areas vital for sustaining agricultural services and ecosystem resilience. This approach will facilitate informed decision-making and promote the long-term sustainability of agricultural systems in the Cultivar territory.

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Appendix 1

Criteria	Proxy indicator (PI)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Time	3	3	4	4	4	2	3	2	4	4	5	2	2	3	4	3	1	5	4	5
Complexity	4	3	4	2	2	1	2	2	2	3	4	1	1	2	3	2	1	5	4	5
Relevance	5	3	5	5	4	4	3	3	4	3	5	2	3	3	3	2	3	4	4	4
Spatial	5	3	5	5	2	1	2	2	3	3	5	1	3	3	4	2	1	5	4	5
Mean	4.3	3.0	4.5	4.0	3.0	2.0	2.5	2.3	3.3	3.3	4.8	1.5	2.3	2.8	3.5	2.3	1.5	4.8	4.0	4.8

Appendix 2

Data	Reference
Portugal's official administrative map	https://dados.gov.pt/pt/datasets/carta-administrativa-oficial-de-portugal-caop2023-continente/ (2024.02.01)
Recreation infrastructure	https://wiki.openstreetmap.org/wiki/AND_data (2023.12.01); https://sig.icnf.pt/portal/home/item.html?id=129cf7386d4f4392a71 549b3893b87c2 (2024.02.01)
Citizen science	https://doi.org/https://doi.org/10.15468/hsa3kw via GBIF.org (2023.03.13)
Land use Land cover (COS 2018)	https://dados.gov.pt/pt/datasets/carta-de-uso-e-ocupacao-do-solo-2018-1/ (2023–03-06)
Coats of arms with AE motif	https://dados.gov.pt/pt/datasets/freguesias-de-portugal/ (2024.02.01)
Protected Areas	https://dados.gov.pt/pt/datasets/rede-nacional-de-areas-protegidas-rnap/ (2024.02.01)
National Agricultural Reserve	https://www.dgadr.gov.pt/reserva-agricola-nacional-ran (2024.02.01)

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The Relevance of Safety and Health at Work Literacy in SDG8

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Abstract. It is essential for future sustainability to promote work that contributes to preserving the environment, but for true sustainability it is essential that these workplaces are also decent and safe for all workers, in line with SDG 8. Occupational health and safety literacy, for both workers and employers, is essential for preventing and reducing accidents at work and occupational illnesses, and educational institutions play a key role in this. The aim of this work is to carry out a bibliographical review of scientific publications in order to assess the current state of safety and health at work literacy, future challenges and areas of intervention. This work has shown that, instead of the official term "safety and health at work", more and more studies are opting for the term "occupations health and safety", which represents the growing concern for workers' metal health. This is consistent with the analysis of the various publications mentioned in this study. Other conclusions of this study are that 36.2 per cent of the publications address the importance of decision-makers/employees at the top of the company hierarchy in promoting healthy and safe workplaces, and that 31.9 per cent of the publications focus on the relationship between safe and healthy workplace practices and communication and training strategies for workers, reinforcing the importance of literacy for decent and safe workplaces.

Keywords: Safety and Health at Work · SDG8 · Literacy

1 Introduction

A safe and healthy working environment is vital for global sustainability, influencing the economic and social development of communities. The International Labour Organization (ILO) sets the goal of developing policies and devise programmes promoting decent work for all, and the European Agency for safety and health at work (EU-OSHA) prioritises the circular economy, digitalisation, nanomaterials, and green jobs as emerging risks. A shift to a circular economy is essential for the EU's future sustainability. For

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an effective transition to a circular economy, digital technologies are essential, as is the redesign of tasks associated with changes in organisational processes. Both the digitalisation of the workplace and the shift to circularity present opportunities and challenges for safety and health at work (SHW). One of the potential implications for SHW resulting from digitalisation is a reduction in physical hazards and an increase in psychosocial risks. Others is the decentralised distribution of workers, which makes it more difficult to supervise and control workers' SHW activities, mobile work means that workers are more likely to work in unsafe environments[1].

Jobs that contribute to preserving or restoring the environment are known as green jobs. However, for green jobs to be truly sustainable, it must be ensured that they provide safe, healthy and dignified working conditions for workers. Green jobs need to be good for workers, as well as good for the environment (see Footnote 1).

1.1 SHW and Decent Work

The ILO's objectives include the promotion of safe, healthy, and decent workplaces as part of the basic principles of human rights. The concept of decent work summarises the aspirations of workers in the professional field and incorporates several elements, such as: (1) opportunities to carry out productive work for fair remuneration; (2) security in the workplace and social protection for families; (3) better prospects for personal development and social integration; (4) freedom to express their concerns; (5) organisation and participation in decisions that affect their lives; (6) and equal opportunities and treatment for all workers[2].

This ILO concern is aligned with SDG8, which states "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all". The targets of SDG8[3] reinforce the relevance of SHW concerns and challenges, in particular target 8.3 which refers to the promotion of "development-oriented policies that support productive activities, decent job creation", target 8.5 which refers to the creation of "decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value", and target 8.8 which indicates the need to " Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment".

1.2 SHW in Society and Organisations

Decent work, which guarantees the protection of life and safety, and health at work, is one of the basic principles of human rights. However, the performance of labour duties can often lead to damage of workers' health, including physical and/or psychological damage. The prevention and reduction of accidents at work and occupational illnesses, as well as the preservation and improvement of health, have a major impact not only on the

[1] https://osha.europa.eu/pt/publications/circular-economy-and-safety-and-health-role-digitalisation-circular-economy-and-implications-occupational-safety-and-health-until-2040.

[2] https://www.ilo.org/lisbon/temas/WCMS_650867/lang--pt/index.htm.

[3] https://sdgs.un.org/goals/goal8#overview.

worker, but also on the productivity and economy of organisations. Therefore, awareness needs to be raised so that investment in SHW is not perceived as an unnecessary expense or a huge cost, but as a profitable long-term investment whose main focus is on employers and workers, and consequently on society. In this sense, a strong commitment from employers is essential, along with a high level of involvement and participation from workers. Integrating SHW issues into the early education of workers and employers is essential in raising their awareness of SHW[4,5].

Undoubtedly, education can be seen as a transversal strategy associated with a culture of safety for future generations, by strengthening skills and broadening knowledge. SDG4, which seeks to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all", can be seen as a critical component in dealing with SHW issues, through a preventative approach rather than a reactive one. OSHA emphasises that integrating SHW topics into the various levels of education is part of a strategy to raise awareness and prevent attitudes, to help reduce accidents and improve the safety culture in the workplace (Kavouras et al., 2022).

Proper management of occupational risks promotes compliance with safety rules as part of a preventive policy and is essential for reducing the probability of accidents at work and occupational illnesses. Management board must prioritise actions to ensure safe and healthy working conditions, including measures focused on workers (Nunes, 2022). Implementing a culture of prevention in society and strengthening citizens' health and safety literacy, for example through specific communication and awareness-raising for certain target groups, as well as early education in safety and health, helps to neutralise SHW risks (Hauke et al., 2022). Thus, promoting workers' literacy is one of the main measures for increasing their awareness of occupational risks, contributing to improvements in working conditions from an occupational health and safety perspective (see Footnote 4).

It is possible to find statements in scientific publications to the effect that "Compliance with basic safety and health rules is dependent on the individual's ability to understand and subsequently apply them." In addition, "It is the responsibility of the board with responsibility in these areas to disseminate behaviours that promote safety and health through information and training actions (Luís & Luís, 2013)." Although the work of Luís & Luís (2013)is directly related to public health safety, investment in worker training is essential and unequivocal in guaranteeing the safety of the population.

Another aspect to consider today that has consequences for safety and health in the workplace, particularly workers' mental health, is the globalisation of technological advances in industry, especially in the digital industry (Kralj & Aralica, 2023; Tan et al., 2023). In this sense, some studies refer to the adoption of mental health programmes following the increase in psychosocial risks in organisations (Kavouras et al., 2022; Oates & Hassan, 2020).

4 https://oshwiki.osha.europa.eu/en/themes/osh-general.

5 https://osha.europa.eu/en/publications/factsheet-77-business-benefits-good-occupational-safety-and-health.

1.3 SHW and Worker Literacy

As well as being an EU legal requirement, workers' awareness, training, and information on SHW is essential, allowing them to recognise potentially dangerous work situations in time, the risks they may be exposed to, as well as the symptoms and signs of any work-related illness (see Footnote 4). This ability of the worker to recognise what has been conveyed in training and information at work is called literacy. Teachers/trainers play an important role in transmitting information, which should be aimed at developing positive attitudes and understanding the importance of preventing accidents and occupational diseases, in other words, for workers' SHW literacy (Horvat, 2019). Scientific publications state that educational institutions should follow current trends through digital platforms in order to improve the skills and literacy of young students (Ceballos et al., 2021), and that learning methodologies should be supported by materials with an appealing design, with clear and understandable information (Grabowski, 2019; Shannon & Parker, 2020; Sinyai & Barlet, 2020). Teachers/trainers influence the maintenance of safe and healthy workplaces from the first days of a young adult's labour activity until the end of their working life. By ensuring that future young professionals are empowered with SHW knowledge and skills, a culture of safety will be promoted, which will become an integral part of the work process, developing an appropriate attitude towards the importance of SHW, and throughout their professional career (Horvat, 2019).

It was documented and assumed that young workers are at greater risk of injury at work than other workers (Turner et al., 2022). How young workers respond to hazards at work depends on their safety training and is one of the causes of accidents at work. However, factors such as inadequate supervision and work arrangements that undervalue or devalue the dangerous situations present in the work environment should also not be overlooked as causes of accidents at work and occupational illnesses (Turner et al., 2022). Analysing a number of scientific publications, it is stated that training and information are important for guaranteeing safe and healthy working conditions (Lari et al., 2021; Savković et al., 2019) and that it is also essential to have regulations associated with SHW (Abiayi et al., 2015). Other authors have found that a higher level of literacy among workers, i.e. a higher level of education, also boosts knowledge and attitudes that are suitable for implementing SHW practices and measures (Friedrich et al., 2023; Koch & Nienhaus, 2022).

Integrating SHW into the school curriculum is a priority, with a view to fostering a culture of prevention in young people, developing responsible attitudes in both their personal and professional lives. It is pertinent to value and define guidelines for improving educational and organisational performance, integrating SHW into the teaching and learning process in school curricula in order to reduce accidents among future workers (Burgos-Garcia, 2018).

Educational institutions play a fundamental role in promoting literacy among young people in a wide range of areas, with SHW being a key area in order to guarantee safe and healthy working conditions. The aim of this work is to carry out a bibliographical review of scientific publications on the Scopus in order to assess the current state of SHW literacy, future challenges, and potential areas of intervention.

2 Methodology

Various researchers have analysed the importance of employee literacy from different perspectives, in different areas of activity, so it was considered pertinent to assess the "state of the art" of scientific studies in this area that have been published in the last 8 years (2015 to 2023), and its relationship to the promotion of safe and decent workplaces. To this end, the number of scientific articles referenced in Scopus was analysed, based on specific words, by searching in the "Article title, Abstract, Keywords" field. This study aims to analyse information from scientific papers that relate the SHW literacy of workers or future workers to the various problems associated with this area, namely levels of accidents at work and occupational illnesses.

The first stage of the methodology involved defining the search terms and analysing the information published and disseminated in this field. Since it is not always easy to distinguish between literacy and workers' skills, the approach defined by the authors prioritised the keyword literacy in view of the aim of this study. Despite this choice, the keyword "skills" was also considered. In the context of SHW, the keywords that were also considered relevant by the authors when predefining the methodology were "safety and health at work", "safety at work", and "health at work". However, in English-language research, it is common for the SHW area to be referred to as "occupational safety and health" or "occupational health and safety", so these terms were also considered, according with the analysis in Sects. 3.1 and 3.2.

In support of this first stage, two tasks were carried out: (a) analysis of the main terms used by national and international organisations / public board directly linked to this area; (b) analysis of the number of results per keyword between 2000 and 2023. The data obtained and its analysis will be discussed in Sect. 3.1.

In the second stage of this methodology, by searching in the "Article title, Abstract, Keywords" field and using the Boolean operator "and". The search results were counted and analysed (Sect. 3.2). Each set of search terms was assigned a code according to Table 1.

Table 1. Codes associated with research carried out on the Scopus

LSHW	"literacy" AND "safety and health at work"
LSW	"literacy" AND "safety at work"
LHW	"literacy" AND "health at work"
LOSH	"literacy" AND "occupational safety and health"
LOHS	"literacy" AND "occupational Health and Safety"
SSHW	"skills" AND "safety and health at work"
SSW	"skills" AND "safety at work"
SHW	"skills" AND "health at work"
SOHS	"skills" AND "occupational health and safety"
SOSH	"skills" AND "occupational safety and health"

It should be noted that: (1) results with "no author name available" and/or no abstract of the publication available were immediately excluded; (2) by choice of the authors, in line with the study's objective, priority was given to keyword literacy, and therefore the abstracts of the SOHS and SOSH research results were not analysed.

3 Results and Analysis

3.1 Keyword Analysis

Although Portuguese legislation refers to this area of activity as "Safety and Health at Work" (SHW) (Portuguese Law 3, 2014[6]), not all organisations and entities use this nomenclature in a common way, especially at the international level. As already mentioned in the methodology, the choice of keywords to search in the field of SHW was based on a priori research of the terms most used by some Portuguese organisations relevant to this scientific area, namely the Authority for Working Conditions (ACT – *Autoridade para as Condições do Trabalho*), the National Health Service (SNS - *Serviço Nacional de Saúde*), and the General Manager for Health (DGS - *Direção Geral de Saúde*), and international organisations such as the International Labour Organisation - Lisbon (ILO), the International Labour Organisation (ILO); and the European Agency for Safety and Health at Work on the website in Portuguese (OSHA_pt) and English (OSHA_en). Table 2 summarises the main terms used by these organisations. It should be noted that the DGS defines Occupational Health as "an area of intervention that values the workplace as a privileged space for the prevention of professional risks, the protection and promotion of health and workers' access to health and safety work Services". (https://www.dgs.pt/saude-ocupacional/apresentacao6.aspx)."

Table 2. Main terms used by some organisations.

ACT	Safety and Health at Work / Safety, health, and well-being at work
OIT Lisbon	Safety and Health at Work
ILO	Safety and Health at Work / Occupational Safety and Health
OSHA_pt	Safety and Health at Work
OSHA_en	Safety and health at work / Occupational Safety and Health
SNS	Occupational Health
DGS	Health and Safety at Work / Occupational Health

Considering the results shown in Table 2 and the aim of the study, the number of results per keyword was analysed, as shown in Table 3. This analysis covered a long period of time, from 2000 to 2023, allowing for a broader historical analysis.

These results show that the number of publications with the word "literacy" increased from 215 to 8466 (39.4 times) in the study period, and publications with the word "safety"

[6] https://diariodarepublica.pt/dr/legislacao-consolidada/lei/2009-56365341-106425817.

increased from 13227 to 71252 (5.4 times). These facts suggest that there is a growing concern on the part of scientific promoters and society in general about these issues.

Table 3. Number of results per keyword from 2000 to 2023

	2000	2010	2015	2017	2019	2021	2023
literacy	215	1657	3165	4015	5496	7225	8466
safety	13227	43880	52139	56064	60440	77091	71252
safety at work	0	17	14	24	29	21	14
health at work	1	10	16	13	22	15	18
safety and health at work	0	7	7	4	13	5	10
health and safety at work	0	6	0	7	8	4	6
occupational safety	609	595	720	651	846	1121	726
occupational health	1483	2034	2423	2119	2748	2865	2213
occupational health and safety	16	95	168	153	275	258	265
occupational safety and health	181	173	222	159	217	205	143

At this stage of the study, there was a preference for using the term "occupational" associated with health and safety, with publication number values of several hundred, over the term "work", with publication number values of less than 30. Looking in more detail at the terms searched, Fig. 1 clearly shows a very significant increase in the use of the term "occupational health and safety" from 2000 to 2019, despite national and international organisations not using it as their first choice. The use of the term "occupational safety and healthy" shows a pattern of a relatively constant number of publications, with the biggest decrease occurring between 2021 and 2023 with a decrease of 7.6%.

These data are also the result of an increase in the relevance of occupational health, with organisations themselves reinforcing their campaigns using the terms "safe and healthy workplaces" (OSHA), "Digital platform work: implications for occupational safety and health"[7], "Protecting workers' health"[8]; or "Occupational health for companies"[9].

3.2 Analysing the Relevance of Publications on SHW Literacy and Skills

As described in the methodology, this stage presents the results obtained from the search in the "Article title, Abstract, Keywords" field referenced in Scopus, considering the assumptions presented below in the respective order of priority (Table 4).

[7] https://healthy-workplaces.osha.europa.eu/pt/publications/digital-platform-work-implications-occupational-safety-and-health-0trabalho%20digno,%20saúde%20ocupacional.

[8] https://www.who.int/news-room/fact-sheets/detail/protecting-workers'-health.

[9] https://www.sns.gov.pt/noticias/2020/04/28/saude-ocupacional/

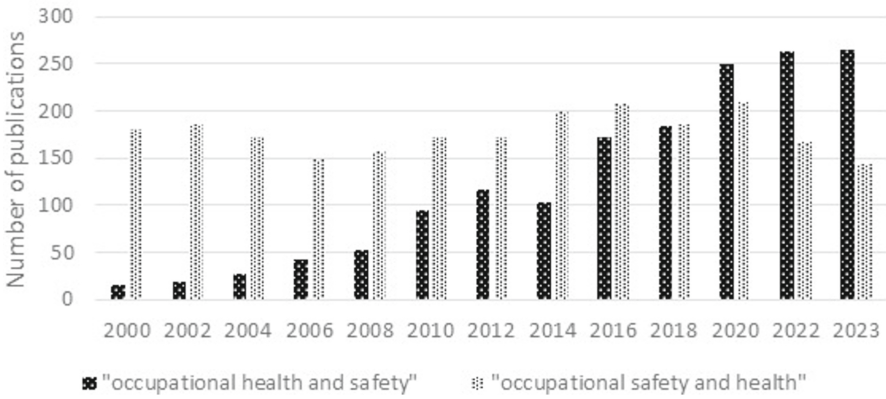

Fig. 1. Evolution of the number of publications for the terms “occupational safety and health” and “occupational health and safety”, between 2000 and 2023.

a) Total number of publications per search.
b) Number of publications excluding repeats and those already considered in previous searches.
c) Final number of publications analysed in the field of SHW, based on the information in the abstract, which represents a total of 69 publications.

Table 4. Number of results for searches in the “Article title, Abstract, Keywords” field.

Codes	Search terms	(a)	(b)	(c)
LSHW	“literacy” AND “safety and health at work”	0		
LSW	“literacy” AND “safety at work”	3	3	3
LHW	“literacy” AND “health at work”	4	4	3
LOSH	“literacy” AND “occupational safety and health”	17	17	13
LOHS	“literacy” AND “occupational Health and Safety”	18	15	13
SSHW	“skills” AND “safety and health at work”	4	4	4
SSW	“skills” AND “safety at work”	31	29	18
SHW	“skills” AND “health at work”	24	19	15
SOHS	“skills” AND “occupational health and safety”	135	-	-
SOSH	“skills” AND “occupational safety and health”	123	-	-

When analysing the abstracts of the articles obtained by this methodology, all of which made common reference to the importance of workers’ literacy for a better guarantee of SHW conditions, namely levels of accidents at work and occupational diseases, specific patterns were found in the 69 scientific articles, namely (1) the association of safe and healthy working practices with communication and training strategies for workers

(31.9%); (2) the language comprehension difficulties associated with non-native workers (11.6%); (3) the importance of policy-makers and managers, and other workers at the top of the hierarchy of companies and public organisations in promoting a culture of safety and healthy workplaces (36.2%); (4) and the importance of educational institutions in guaranteeing SHW literacy and skills for workers (20.3%). Several publications focus specifically on psychosocial risks, namely workers' mental health and its implication in SHW conditions (23.2%), although this problem is often associated with one or more of the factors described before.

The association of safe and healthy working practices with communication and training strategies for workers is associated with a lack of knowledge of how to identify and act when exposed to chemical and biological risks (Abiayi et al., 2015; Eickholt, 2023; Lari et al., 2021; Messias & Nascimento, 2019), as well as physical and mechanical risks (Eickholt, 2023; Torun, 2023). Also, in this area of communication strategies, the importance of the way information/training is transmitted and understood by the target audience is mentioned. The importance of images over text is mentioned, as it is not only more attractive, especially for workers with lower levels of training, but also for workers who have difficulties in the native language of the countries where they are working. The fact that these non-native speaking workers don't understand the message is a negative factor, as well as the fact that those responsible don't always make the effort to find solutions for transmitting information (Lari et al., 2021; Sinyai & Barlet, 2020; Suthakorn et al., 2020). Some of the publications analysed report strategies to promote better communication, understanding and internalisation of information in the area of SHW, including the use of digital media to prevent mechanical risks, as well as to maintain workers' mental health (Kralj & Aralica, 2023; Rapp et al., 2019).

The importance of policymakers and managers in promoting a culture of safety and healthy workplaces is also a predominant theme when analysing the abstracts of the selected publications (Oates & Hassan, 2020; Vadulina et al., 2021). Despite finding this pattern in the publications associated with the different search terms, it should be emphasised that the three results of the LHW search fall into this pattern, as do 73% of the results of the SHW search, i.e. research related to "heath at work" is closely linked to this publication pattern. It was also found that of the 25 publications that fall into this pattern, 15 are directly linked to psychosocial risks, namely the promotion of programmes to increase the mental health literacy of organisational leaders, and to establish clear guidelines to prevent psychosocial risks, urging political and business decision-makers about their fundamental role in preventing and minimising exposure to psychosocial risks for workers in the workplace (Brugière et al., 2023; Dimoff et al., 2016; Nexø et al., 2018; Pavlista et al., 2021).

In terms of the importance of educational institutions in guaranteeing SHW literacy and competences for workers, there is a direct link between workers' qualifications and a reduction in the risk of accidents at work and occupational illnesses (Delgoulet & Santos, 2022; Hauke et al., 2022; Karl & McDaniel, 2018; Kavouras et al., 2022). The importance of the syllabus of higher education and specific training courses is also mentioned as a strategy for achieving low levels of accidents at work and occupational illnesses (Čolić et al., 2021; Eickholt, 2023).

4 Conclusions

Promoting and guaranteeing decent, healthy and safe workplaces is one of the basic human rights and is set out in SDG8. It is therefore essential to raise awareness, train and inform workers and employers to prevent and reduce accidents at work and occupational illnesses. In the first stage of this work, there was a significant increase in the number of scientific publications using the terms literacy and safety, as well as an increase in the term "occupational health". This is consistent with the data obtained in the second stage of this work, i.e. the number of publications with the word "occupational" is higher than the number of publications with the word "work", despite the fact that this word is part of legal and institutional documents.

In the analysis of the publications selected in the second part of this paper, it was found that 36.2% of the publications address the importance of policymakers and managers, and other workers at the top of the company hierarchy to promote healthy and safe workplaces, and 31.9% of the publications relate safe and healthy work practices to communication and training strategies for workers. Psychosocial risks are also extensively addressed, accounting for 23.2% of publications.

In the publications analysed, it is common to find concerns about the lack of training for non-native workers and/or those with precarious jobs, and the consequent increase in exposure to occupational risks on the part of these workers. In line with the SDG8 targets, various strategies are put forward, such as the use of images and digital tools, to address these workers' lack of SHW literacy.

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Application of Red Mud in Additive Manufacturing of Geopolymers for Heavy Metal Adsorption

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Abstract. Industrial activity is widely recognized for its significant contribution to environmental issues, notably the generation of solid waste and contamination of water bodies with heavy metals. To address these challenges, an innovative approach utilizing printed geopolymers made from industrial waste has been developed for heavy metal adsorption. These geopolymers were formulated using two types of industrial waste, fly ash and red mud, along with metakaolin. Sample composition was varied while keeping the fly ash quantity constant and altering the proportion of red mud. Four distinct formulations were prepared, with ratios between red mud and fly ash ranging from 1 to 1.1. To assess the impact of red mud quantity on heavy metal adsorption capacity, adsorption experiments were conducted using cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and lead (Pb) as reference ions over an 8-h period. The results revealed a trend of greater efficiency in heavy metal adsorption by samples containing a higher proportion of red mud. Particularly, lead exhibited the highest adsorption capacity, with averages of 77.61% and 90.42% adsorption for samples with red mud/fly ash ratios of 1 and 1.07, respectively. These findings were attributed to the increased roughness observed in the filaments of samples with higher red mud content, resulting in a larger available surface area for adsorption, thus conferring superior efficacy in removing heavy metals from the environment.

Keywords: Geopolymer · Red Mud · Adsorption

1 Introduction

Geopolymers are materials composed of an aluminosilicate source and an alkaline activator [1]. These materials have the capacity to replace cement-based binders, demonstrating comparable performance in various applications. In addition, replacing cement with geopolymer significantly reduces greenhouse gas emissions [2]. Metakaolin, derived from the calcination of natural clays rich in kaolinite, is a commonly utilized aluminosilicate source. Its production process, occurring within the temperature range of 500 to 900 °C, is associated with significant carbon dioxide emissions [3].

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In order to enhance the sustainability of geopolymers, industrial by-products such as red mud and fly ash can serve as viable alternatives to metakaolin. The presence of alumina and silica in these wastes renders their composition appealing for geopolymer production. Presently, numerous research endeavors are focused on the advancement of geopolymers utilizing fly ash and red mud for diverse applications, including civil construction [4, 5], sorbents [6, 7], and pH regulators [8, 9]. In addition to these applications, geopolymers have proven to be efficient materials when it comes to removing heavy metals from water.

Several noteworthy attributes of geopolymers have positioned them as promising and environmentally friendly alternatives to conventional materials for heavy metals adsorption. This is primarily attributed to their sustainable manufacturing process, which involves the utilization of waste streams or by-products and boasts low energy consumption [10]. The analogous zeolite structure of geopolymers imparts exceptional adsorbent properties, facilitating the effective removal of heavy metals from wastewater. Geopolymers exhibit properties akin to zeolites, showcasing a high capacity for cation exchange and a pronounced affinity for cationic heavy metals, owing to the presence of aluminum within the geopolymer matrix [11, 12]. The use of solid waste in the composition of geopolymers has a positive effect in metal adsorption. The presence of metallic oxides and inorganic salts in industrial wastes enhances the active sites on the surface of the geopolymer, facilitating a combined contribution of cation exchange, ionic precipitation, and ion complexation with heavy metals [13, 14].

The interest in producing geopolymers for heavy metal adsorption via 3D printing is justified by the potential to achieve a high surface area with printed porosity [15, 16]. It has been observed that a greater surface area enhances the adsorption of heavy metals by providing more functional groups across the surface [17].

Given these considerations, the primary objective of this study is to assess the influence of red mud quantity on the adsorption of heavy metals in printed geopolymers. In addition to red mud, geopolymers utilize metakaolin and fly ash as sources of aluminosilicate. The heavy metals evaluated in the adsorption process include copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), and cobalt (Co). Adsorption was evaluated over an 8-h period, and the morphological characteristics of the filament samples were correlated with the final results obtained.

2 Materials and Methods

2.1 Materials

To produce the geopolymer samples, metakaolin (MK), fly ash (FA) and red mud (RM) were used as aluminosilicate sources. The chemical composition of the aluminosilicate sources is shown in Table 1.

A solution of sodium hydroxide, sodium silicate and water was used as an alkaline activator. For every gram of water, 1.057g of sodium hydroxide and 7.496g of sodium silicate were used. To adjust the viscosity of the printing paste, PEG 600 was used as an additive.

Table 1. Chemical composition of metakaolin, fly ash and red mud.

Oxides (%)	**MK**	**FA**	**RM**
Na_2O	0.075	1.031	5.641
MgO	0.265	2.278	0.334
Al_2O_3	40.062	14.622	18.595
SiO_2	52.070	50.548	9.995
CaO	0.134	13.115	8.741
Fe_2O_3	1.851	5.421	40.229
TiO_2	1.997	0.885	5.552
Median Size (μm)	2.88	20.14	1.41

2.2 Sample Compositions and Preparation

To evaluate the effect of the amount of red mud on the adsorption of heavy metals, four compositions with different amounts of mud were evaluated. The rest of the composition was kept constant. Table 2 shows the quantities of each component, by mass, for each of the compositions.

Table 2. Composition of pastes for printing geopolymers.

Paste	**MK (g)**	**FA (g)**	**RM (g)**	**A.A* (g)**	**Water (g)**	**PEG (g)**	**RM/FA****
3.40RM	3.07	3.07	3.40	6.50	0.50	0.12	1.10
3.30RM	3.07	3.07	3.30	6.50	0.50	0.12	1.07
3.20RM	3.07	3.07	3.20	6.50	0.50	0.12	1.04
3.07RM	3.07	3.07	3.07	6.50	0.50	0.12	1.00

*Alkali Activator; **Ratio between the mass quantity of red mud and fly ash

All samples followed the same preparation procedure, consisting of: (I) Mixing of the powdered materials; (II) Addition of water and the additive; (III) Addition of the alkaline activator; (IV) Mixing for 3 min; (V) Pause in the mixing process to remove adhered material from the sides of the mixing container; (VI) Mixing for an additional 3 min.

2.3 Methods

For the adsorption experiments, samples with dimensions of 1.5 × 1.5 × 1 cm were printed using filaments with a diameter of 0.410 mm. Each of the samples has 19 layers, with the direction of the filaments varying by 90 degrees in each one. Thus, the structure of the samples forms a grid that allows the solution with heavy metals to pass through.

Following their production, the samples were allowed to rest in a controlled humidity environment for 24 h, after which they were placed in a 40 °C oven for 48 h. Upon removal from the oven, the samples were left at 25 °C for 25 days prior to each test. Figure 1 shows one of the prepared samples.

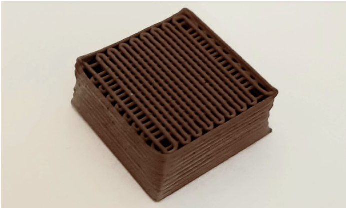

Fig. 1. Geopolymer sample produced by 3D printing.

For the metal adsorption tests, solutions were prepared with Co, Ni, Cu, Zn and Pb, with 25 ppm of each element. Each sample was submerged in 250 mL of the solution containing the heavy metals for 8 h, using a magnetic stirrer to ensure that the solution passed through the sample, as shown in Fig. 2. The solutions were kept at pH 4 throughout the adsorption process and 1M nitric acid was used to control the pH.

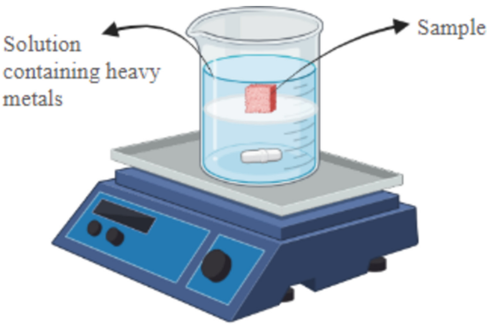

Fig. 2. Schematic of the experimental procedure.

3 Results and Discussions

After the adsorption tests, the amount of each metal adsorbed over time can be analyzed. Figures 3 and 4 show, respectively, the amount of metal adsorbed over the course of the test and the total adsorption of each of the compositions.

An increase in metal adsorption can be observed as the amount of red mud in the samples increases. This phenomenon has been observed before, where geopolymers with a higher RM content show more adsorption of heavy metal ions [18]. This is due to the fact that RM is composed of fine particles with high surface reactivity, thus adsorbing heavy

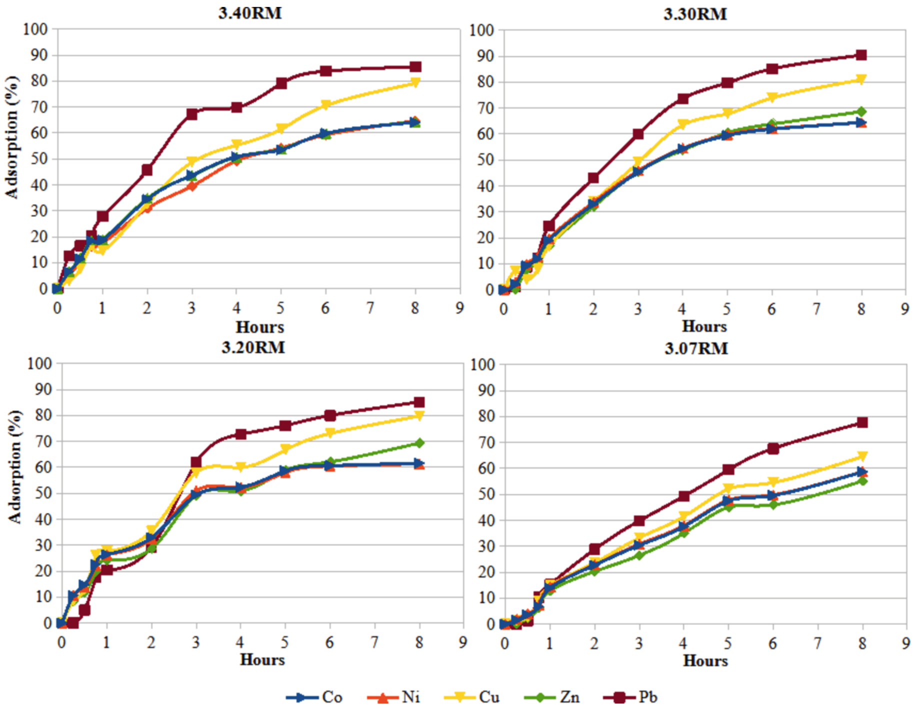

Fig. 3. Adsorption of heavy metals for each of the samples over the 8 h of testing.

metal ions more effectively [19, 20]. The difference in the intensity of adsorption of each of the metals is due to the characteristics of the metal ions, such as the size of hydrated metal ions, their activity, and the hydration free energy [21]. Smaller hydrated metal ions typically have lower hydration free energy, thereby promoting easier adsorption, whereas larger ions tend to exhibit the opposite effect [18].

In addition to RM contributing to adsorption due to its reactivity, the fact that it was added to the pastes in different quantities altered the rest of the composition. Due to their higher dry material content relative to the amount of liquids, pastes with a greater quantity of RM exhibited greater viscosity. With a higher solid-to-liquid ratio, pastes containing more RM became drier and consequently, their printed filaments exhibited increased roughness. To confirm this observation, photographs were taken at a 35x magnification. Figures 5 and 6 show, respectively, the filament roughness of samples 3.30RM and 3.07RM. Geopolymers with larger surface areas tend to be better adsorbents [10]. Because they are rougher, the 3.30RM samples have a larger surface area and, as a consequence, a larger area for adsorbing heavy metals.

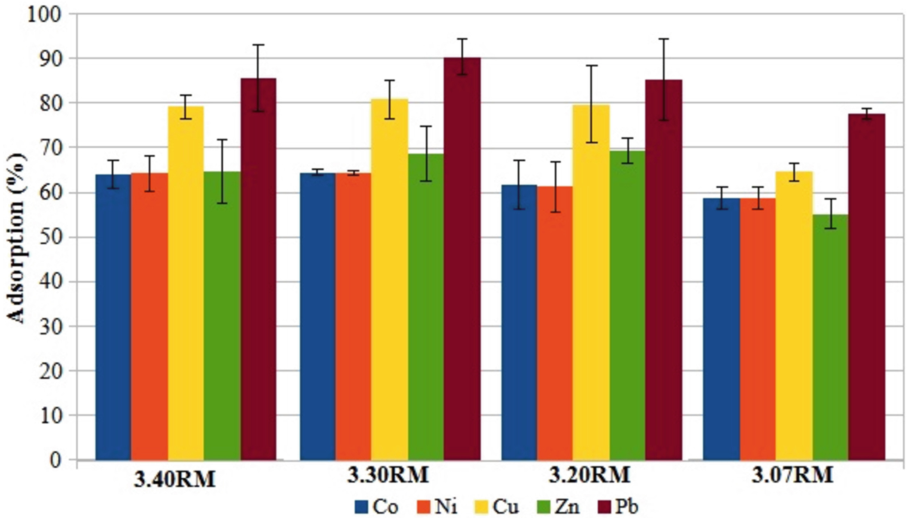

Fig. 4. Total adsorption of each metal for each of the samples.

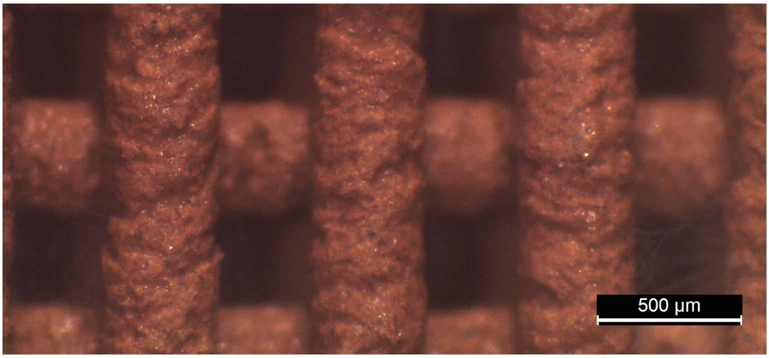

Fig. 5. Filament roughness of samples 3.30RM.

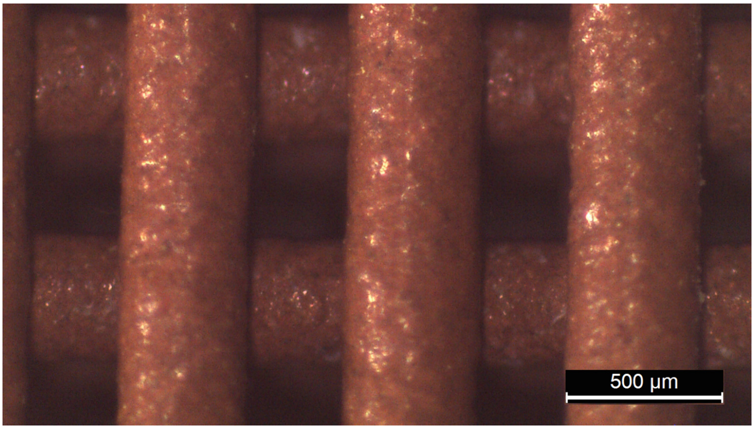

Fig. 6. Filament roughness of samples 3.07RM.

4 Conclusion

Geopolymers represent promising materials for heavy metal adsorption, especially due to their composition incorporating solid waste, thereby enhancing sustainability. The ability to be shaped via 3D printing allows for optimization of geometry, particularly beneficial for adsorbent applications.

Red mud has proven effective in metal adsorption, with higher RM content leading to enhanced efficiency in adsorption. Furthermore, the increased filament roughness in samples, attributed to changes in the rheology of geopolymers, contributed to greater surface area and consequently enhanced metal adsorption capacity. Among the elements investigated, Cu and Pb demonstrated the most significant differences in adsorption percentage between samples. The sample 3.30RM exhibited adsorption rates of 90.42% and 80.90% for Pb and Cu, respectively, whereas the sample 3.07RM showed adsorption rates of 77.61% and 64.58% for each respective element.

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Municipal Household Waste Management Methodologies in the EU Countries: A Reverse Logistics Benchmarking Approach

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Abstract. Through the application of a reverse logistics benchmark approach, this paper aims to investigate prevailing waste management practices in the European Union (EU) countries. In detail, it will analyze existing waste management practices, identify successful efforts, and identify areas for improvement within the EU region, in order to answer how can different collection waste management practices promote sustainability and integrate with reverse supply network? In this article, a structured literature review is carried out to examine the existing literature background, and public reports are collected and analyzed published by EU nations on waste management. The aim of the article is to understand their current state and evaluate the applicability of reverse logistics techniques in enhancing waste collection, recycling, and disposal. By answering the research question, the examination can provide valuable insights and recommendations for policymakers, as well as those involved in managing waste or stakeholders with an interest in enhancing the sustainability and efficiency of waste management practices in EU countries.

Keywords: Reverse Logistics · Waste Management · Sustainability

1 Introduction

According to the European Commission, the effective management of waste and its recycling in an environmentally friendly manner, along with harnessing the secondary materials they encompass, stand as fundamental components of the EU's environmental strategy. The objective of EU waste policy is to advance the concept of a circular economy by maximizing the extraction of high-quality resources from waste. Aligned with this vision, the European Green Deal seeks to foster economic development through the transition towards a contemporary, resource-efficient, and competitive economy. At the core of managing waste within the EU lies the Waste Framework Directive, serving as the legal foundation for the treatment and handling of waste, establishing a hierarchical approach to waste management (European Commission 2022).

Given the diverse nature of waste, specific strategies are required for different categories. The EU has instituted a range of regulations tailored to address distinct

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types of waste. These categories include Batteries and Accumulators, Biodegradable Waste, Construction and Demolition Waste, End-of-Life Vehicles, Landfill Waste, Mining Waste, Packaging Waste, Polychlorinated Biphenyls and Polychlorinated Terphenyls (PCBs/PCTs), Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS), Sewage Sludge, Ships, Waste Containing POPs, Waste Oil, Waste Shipments, and Waste from Electrical and Electronic Equipment (WEEE) (European Commission 2022). According to EU Commission data, the typical European generates approximately 5 tonnes of waste annually. Recycling rates within the EU stand at just 38%, highlighting a significant portion of waste that is not effectively managed. Furthermore, in certain EU nations, more than 60% of household waste still finds its way to landfills. The overarching goal of EU waste policy is multifaceted. It seeks to safeguard both the environment and human health while facilitating the EU's shift towards a circular economy. To achieve this, the policy establishes clear objectives and targets aimed at enhancing waste management practices, fostering innovation in recycling technologies, and reducing reliance on landfills as a disposal method (European Commission 2022).

The regulations set by the EU regarding packaging encompass all forms of packaging and packaging waste that enter the European market. This includes packaging materials across various sectors, such as industrial, commercial, household, and others. By the end of 2024, member states of the EU are required to establish producer responsibility schemes for all types of packaging. Additionally, the Directive outlines specific recycling targets, as detailed in Table 1. Given this context and the focus of this research, it is crucial for EU countries to attain the specified recycling percentages. This necessitates a significant emphasis on the initial phase of the process, namely the implementation of appropriate and efficient waste collection methods which are vital to ensure the transportation of waste to designated recycling facilities, achieving recycling targets.

Table 1. Recycling % targets for EU Countries (European Commission 2022)

Packaging type	Current targets (%)	By 2025 (%)	By 2030 (%)
All packaging	55	65	70
Plastic	25	50	55
Wood	15	25	30
Ferrous metals	50 (incl. Al)	70	80
Aluminium	–	50	60
Glass	60	70	75
Paper and cardboard	60	75	85

The waste management process commences with the collection phase, followed by transportation, recovery (inclusive of sorting), and waste disposal, encompassing supervision of these operations, extending to the after-care of disposal sites, and incorporating activities conducted as a dealer or broker.

This study specifically focuses on the "collection" phase, which involves the gathering of waste, including initial sorting and temporary storage of waste intended for transportation to a waste treatment facility. To achieve this, potential projects, methodologies, approaches, practices or initiatives were identified by reviewing published literature from EU countries. Subsequently, these identified approaches were evaluated based on their potential to meet the recycling targets stipulated by the EU Commission, to increase sustainability, and to their potential of better integration with the reverse supply network. Additionally, this research concentrates on the methodologies used for gathering municipal solid waste. According to the Organization for Economic Cooperation and Development, municipal waste encompasses household waste as well as waste that bears similarities in nature and composition to household waste (European Commission 2022). Waste management and reverse logistics stages in the waste context have the same phases, so this study took into consideration the waste collection methods in the EU countries from the reverse logistics point of view. That means the collection methods, projects, or initiatives were evaluated based on their proposed abilities to effectively distribute waste to the different channels of the upstream supply chain.

The ultimate goal is achieving environmental sustainability, which involves preserving the environment and ensuring that nature is not exploited as an endless resource pool (Iyer 2020). This concept is intertwined with sustainable development, which refers to progress that fulfills current needs while preserving the potential for future generations to fulfill their own needs (Ducoing 2019). In response to sustainability concerns, numerous industries have embraced the concept of closing the loop within their supply chains, leading to a more intricate process characterized by circular or multi-circular structures, involving various reverse flows of goods, parts, and materials (Simonetto et al. 2022).

In conclusion, the European Union's waste management policies underscore the significance of efficient waste handling and recycling to foster a circular economy and mitigate environmental degradation. The Waste Framework Directive and associated regulations establish a structured approach to waste management, emphasizing the need for improved recycling rates and reduced reliance on landfills. However, achieving these goals requires effective waste collection methods, which serve as the initial step in the waste management process. This article delves into three categories of waste collection methods gleaned from diverse resources: Traditional Waste Management Practices and Countries Performance, Deposit Refund System Application, and Innovative Collection Method. By examining these methodologies, the study aims to assess their potential to enhance recycling rates, promote sustainability, and integrate seamlessly with reverse supply networks, ultimately contributing to environmental preservation and sustainable development.

2 Methodology

This article undertakes a rapid structured literature review to investigate the impact of various waste management practices in EU countries on recycling rates, sustainability promotion, and integration with reverse supply networks. Employing a structured literature review methodology, the study adopts a rigorous and systematic approach to analyzing existing academic literature on the subject matter. This method aims to offer an unbiased and comprehensive understanding of the current knowledge landscape, identifying gaps, patterns, and trends within the field (Dumay et al. 2016). The process entails defining the research question which is "How can different collection waste management practices promote sustainability and integrate with reverse supply network?", To answer it by conducting thorough searches across reputable databases such as Science Direct and WOS, and critically evaluating selected literature to extract pertinent insights. Additionally, information from reliable websites supplements the review, providing valuable perspectives on the topic. The main keywords used in the research were municipal solid waste, collection, waste management, deposit refund systems, Europe, and sustainability. To make sure to cover wider parts of the literature, sub-keywords were used and multi-combinations, such as: ("municipal solid waste" OR "Households waste") AND ("collect" OR "collecting" OR "collection") AND ("Europe" OR "EU") AND "sustainability". ("product return machine" OR "Deposit systems" OR "Refund systems" OR "Return Systems" OR "Reverse Vending Machines") AND "recycling" AND ("EU" OR "Europe"). ("deposit refund systems" OR "DRS" OR "Reverse Vending Machines" OR "deposit return systems") AND ("Europe" OR "EU") AND "waste management". The notable thing was the extremely low number of publications in this area, especially empirical or practical case studies, which can provide more accurate comparisons and results.

3 Results and Discussion

3.1 Traditional Waste Management Practices and Countries Performance

The pay-by-the-bag system bills households for garbage disposal based on waste weight, determined by scales on garbage trucks. Compared to volume-based fees, like unit-pricing, this aligns costs more accurately with disposal. Effective pay-by-the-bag systems rely on comprehensive segregated material collection for recycling. Implementation hinges on residual waste collection costs. Specific garbage bags or stickers/tags must be purchased for disposal, with only tagged garbage collected. This approach significantly reduces the residual household waste collected in Belgium (Gellynck et al. 2011).

Chioatto et al. (2023) examined the transition of waste management practices towards sustainability across four member states: Italy, France, Germany, and the Netherlands, spanning from 2008 to 2013. Findings reveal that regions within Germany and the Netherlands have notably reduced reliance on landfills, instead emphasizing higher recycling rates, while Italy and France exhibit lower performance levels, although with steady advancements over time. It becomes evident that regions with persistently low waste collection volumes must expedite their efforts to meet EU targets. Prior to 2002, landfills stood as the primary choice for managing municipal solid waste (MSW) in Portugal, reflecting the formidable task of shifting towards more eco-conscious disposal methods. The decline in the count of municipal solid waste recovery and treatment systems from 40 to 23 from 1997 to 2010 underscores the struggle to streamline waste recuperation and treatment mechanisms, signaling the necessity for a concerted and exceptional endeavor (Teixeira et al. 2014).

Various waste management systems are implemented across different European countries, each tailored to their unique needs and circumstances. In Germany and the

Netherlands, for instance, source separation systems are in place, requiring households to segregate their waste into distinct categories for recycling purposes. Contrastingly, the United Kingdom adopts single-stream collection systems, where all waste is collected together and later sorted at a centralized facility. Sweden has embraced door-to-door collection systems, streamlining waste collection directly from households. Meanwhile, countries like France and Spain rely on communal collection points or bring in banks, providing residents with designated locations to deposit their recyclable waste. The choice of waste management approach is influenced by various factors, including collection methods, separation techniques, and logistical arrangements. Emphasizing a holistic perspective, it is essential to consider the diverse types of waste when designing a reverse supply chain for municipal solid waste recycling. This comprehensive approach ensures effective and sustainable waste management practices across different regions (Bing et al. 2016).

The EU Landfill Directive (ELD), introduced in 1999, underscores the importance of minimizing landfill usage, advocating for the reduction of biodegradable materials disposed of in landfills. Its implementation catalyzed a transformation in the United Kingdom's municipal solid waste (MSW) management framework resulting in advancements in waste reduction, material recycling, energy recovery, and landfill mitigation. From 2001 to 2016, there has been a notable decline in annual waste generation, plummeting from 463 kg/Ca to 361 kg/Ca. Simultaneously, the proportion of waste recycled and composted surged from a mere 4.6% to a commendable 44.4%, while the portion consigned to landfills dwindled from 54.7% to a mere 7.3%. Moreover, further enhancements can be achieved through comprehensive public education and support initiatives in waste separation at its source (Wang et al. 2020).

According to Gadaleta et al. (2022) in the city of Bari (Italy) three waste collection and management scenarios were evaluated, considering environmental, economic, and socio-technical factors. Scenario 1 (S1) represents the current bring-point system, collecting less than the legal limit of 65% separately. Scenario 2 (S2) aims to maximize separate collection, extending door-to-door service to all neighborhoods, with residual waste managed conventionally. Scenario 3 (S3) combines door-to-door in peripheral areas and bring points in historical areas with a wet/dry system and residue sent to a secondary raw material recovery plant. Results favored S2 as the best scenario, though S3 showed promise with slight deviations: 5.4% and 9.4% in terms of environmental and socio-technical criteria, respectively. S3 costs €58.29/capita, lower than S2's €62.63/capita. The study emphasizes the sustainability of door-to-door systems and innovative material recovery plants. In Finland, waste collection primarily utilizes surface collection containers or deep collection containers, with the former serving commercial waste needs and the latter being underground. Deep collection containers typically incur lower costs due to less frequent emptying requirements and reduced space demands above ground (Piippo 2013).

In Amsterdam, residents have access to street-level and underground waste containers for glass, paper, textiles, and general waste. They can also dispose of bulky waste at recycling centers or arrange for collection. The city provides a website with container locations and guidelines. Residents can "adopt" a container and are encouraged to keep surroundings clean, their role would be in case of waste gets stuck, they can use a special key or notify the city. Additionally, they're encouraged to educate neighbors on proper waste disposal practices (City of Amsterdam 2024).

3.2 Deposit Refund System Application

During the COVID-19 pandemic, Portugal's adoption of the Deposit Return System (DRS) showcased innovation. Initial findings from the pilot indicate that DRS implementation can enhance both the quantity and quality of collected packaging waste, aligning with EU recycling mandates. Though focusing on PET bottles, the pilot contributes significantly to recycling targets and circularity by incorporating secondary-quality recycled material into new packaging. However, wider DRS implementation entails costs, especially for RVM investment, maintenance, and collection operations, crucial for efficient logistics and avoiding delays. Technological advancements in RVMs can enhance user behavior and experience, emphasizing the need for clear package acceptance guidelines and accommodating larger volumes within shorter timeframes to promote recycling and deter fraud. The study recommends exploring the social aspects of DRS, understanding consumer behavior changes, and adapting economic incentives to optimize pilot projects (Martinho et al. 2024).

On the other hand, (Agnusdei et al. 2022) study delves into the environmental implications of glass packaging, emphasizing its higher greenhouse gas emissions compared to plastic and the loss of valuable resources due to improper disposal. Specifically, it investigates the impact of deposit-refund systems (DRS) on glass packaging waste reduction and recycling. The research findings reveal that variations in waste management systems do not significantly influence glass packaging consumption or recycling rates. Interestingly, countries with DRS implementation exhibit lower per capita retrieval of glass packaging compared to those with alternative systems.

Kahlert and Bening (2022) argued that despite the widespread adoption of deposit return systems for bottles, it's evident that solely relying on this approach will not suffice to meet the ambitious recycling targets. The new system, incorporating a Deposit Return System (DRS), presents superior environmental benefits compared to its impacts, thus providing a positive environmental service. However, despite achieving a 90% package return index, the current Extended Producer Responsibility (EPRS) outperforms the DRS in environmental outcomes. This higher recycling rate of the EPRS is attributed to less eco-friendly processes, such as the requirement for new equipment and the less efficient transport of manually recovered packages from small commercial establishments. The impact associated with specific DRS packages (Flow 1) surpasses that of excluded packages (Flow 2) and even exceeds the impact of the total joint flow in the current EPRS, except for certain categories. A critical concern raised is whether the fixation on increasing recycling rates could lead to environmental damage in other crucial categories like climate change, acidification potential, or eutrophication. Decision-makers need to consider these factors when contemplating changes to waste management systems. The unique commercial structure and characteristics of beverage points of sale in Spain, along with the necessity to maintain EPRS for packaging not covered by DRS, suggest that managing both systems concurrently may lead to environmental inefficiencies (Abejón et al. 2020).

Bala et al. (2020) examined the comprehensive Spanish approach to managing one-way food packaging waste and revealed potential environmental enhancements of nearly 10% by optimizing the bulk collection flow through mechanical-biological treatment (MBT) and enhancing the selective collection of light and glass packaging waste. (Warrings and Fellner 2019) stated that recycling rates reported by various countries cannot be straightforwardly attributed to their respective recovery systems. It's only plausible to suggest that a deposit refund system, when combined with selective collection, may result in a higher overall collection rate.

Another study by Cudečka-Puriņa et al. (2019) highlighted the positive impact of increasing public awareness on waste sorting and the subsequent collection of sorted waste. The implementation of a Deposit Return System (DRS) allows for the acceptance of deposit packaging from consumers, facilitating the utilization of designated waste collection areas within local governments. This integration also presents an opportunity for waste management companies to participate in the DRS initiative. Drawing upon successful examples from Lithuania, Estonia, and other EU nations with established DRS schemes, the authors project significant performance indicators one-year post-introduction of the beverage packaging deposit system. These indicators include the recovery of 80% of reusable beverage packaging sold, recycling or recovery of 60% of disposable beverage packaging recovered, a 75% reduction in forest and roadside litter, and a 25% decrease in the cost of cleaning forest and roadside areas.

The success of a deposit-refund system hinges on the active participation and cooperation of various stakeholders, including producers, consumers, retailers, and governments. Depending on the disparity between material flow and deposit flow, such systems can be categorized into three modes: "Reverse Logistics Mode," "Retail Recycling Mode," and "Repo Recycling Mode." Each mode imposes distinct pressures, with the reverse logistics mode facing significant producer pressure due to demands on production and transportation. Conversely, the repo recycling mode places emphasis on collection point construction, necessitating the return of all packaging to recycling points. While certain countries have seen success with deposit-refund systems, this does not guarantee similar outcomes elsewhere. Nonetheless, it's crucial to comprehend existing systems and glean insights from their experiences to inform future implementations; based on three typical deposit-refund systems of beverage packaging in Germany, Sweden and South Australia (Zhou et al. 2020).

3.3 Innovative Collection Method

The Pneumatic Refuse System (PRS) presents a novel waste management solution utilizing underground pipes to transport waste to a central site. Its adoption aligns with circular economy principles, especially in densely populated urban areas, as seen in Italian provinces. A study from Italy stated that the PRS's economic sustainability lies in repurposing organic waste for energy production, reducing costs, and improving environmental conditions. Implementing PRS networks across municipalities on a metropolitan scale saves public funds and reduces CO2 emissions by minimizing vehicular traffic and utilizing anaerobic digestion for energy generation. This integrated approach harmonizes technology, environmental concerns, territorial considerations, and societal needs, enhancing urban living standards. Thus, deploying PRS in high-density urban areas promises a more sustainable and efficient waste management paradigm (Mangialardi et al. 2016).

Envac, a leading Swedish company dominating the trash-tube market, asserts its role in reducing carbon emissions and traffic congestion caused by conventional garbage collection methods while also mitigating pest infestation. Additionally, it provides a means for monitoring individual waste production to enable appropriate taxation by local authorities. This method of underground waste collection was adopted so far by 44 cities worldwide, including Seoul, Doha, and Barcelona. In Stockholm, where over 100 Envac systems serve approximately 120,000 households, residents utilize designated chutes for different types of waste disposal, facilitating efficient sorting. Food waste is directed to biofuel facilities, recyclables to recycling plants, and mixed waste to incinerators. Periodically, a trap door releases the trash bags into an underground network of pipes propelled by powerful fans, reaching a nearby collection facility within a short distance. Subsequently, the waste is loaded onto garbage trucks for transportation to disposal or recycling facilities, reducing emissions significantly compared to traditional collection methods. This streamlined approach allows for a single trip from the collection point to the disposal facility, resulting in a potential 90% reduction in truck emissions. This efficiency has enabled cities to implement a “pay as you throw” tax system. In Bergen, Norway, residents access the vacuum chutes using a key fob linked to their household, enabling authorities to monitor waste disposal, limiting non-recyclable waste disposal with fees, encouraging responsible waste management practices. As a result, plastic recycling has surged by 29%, while non-recyclable waste volumes have decreased by 8%, leading to an estimated annual savings of $2 million in garbage collection expenses (Rivero 2020).

4 Conclusions

Waste management strategies across European countries vary significantly, reflecting diverse approaches tailored to local needs and circumstances. Pay-by-the-bag systems, such as those implemented in Belgium, offer an effective means of aligning costs with waste disposal while incentivizing recycling. Studies examining waste management practices in Italy, France, Germany, the Netherlands, and Portugal underscore the importance of transitioning towards sustainable practices to meet EU targets. Different collection methods, ranging from source separation systems in Germany and the Netherlands to door-to-door collection in Sweden, highlight the adaptability and flexibility required in waste management. The EU Landfill Directive has played a pivotal role in driving advancements in waste reduction, recycling, and landfill mitigation, as evidenced by notable progress in the United Kingdom. Evaluations of waste collection scenarios, such as those conducted in Bari, Italy, and Finland, emphasize the importance of considering environmental, economic, and socio-technical factors to optimize waste management practices.

The examination of various waste management strategies, particularly the implementation of Deposit Return Systems (DRS), highlights both opportunities and challenges in enhancing recycling rates and promoting environmental sustainability in European countries. While studies demonstrate the potential of DRS to increase packaging waste collection and improve recycling rates, there are notable gaps in understanding its comprehensive impact on waste management systems. Research indicates that DRS alone may not suffice to meet recycling targets and requires supplementary measures to address limitations in influencing consumer behavior and packaging quality. The effectiveness of integrating the reverse vending machines or deposit refund system into the waste management systems of EU countries, their impact on reaching the recycling targets settled by the European Commission, and their best sustainable contribution or their sustainability breakpoint need to be investigated as one of the new practices for collecting waste, and an important research gap. Pneumatic refuse system (PRS), which emerges as a promising solution for urban waste management, particularly in densely populated areas. Studies and already existing examples showcase the potential of such innovative approaches in reducing carbon emissions, optimizing waste collection efficiency, and enhancing urban living standards. However, despite the theoretical framework supporting PRS's efficacy, empirical and practical case studies are essential to validate its potential and address existing gaps in the literature regarding its implementation and impact.

Ultimately, achieving sustainable waste management requires a multifaceted approach, encompassing innovative technologies, community engagement, and tailored strategies to address local challenges. These findings provide valuable insights for policymakers and stakeholders seeking to enhance waste management practices and promote environmental sustainability across Europe.

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Do Plants Improve Indoor Air Quality? Myth or Reality? A Case Study in a University Environment Using Treated Wastewater for Plants Irrigation

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Abstract. Indoor air quality (IAQ) in buildings has a significant influence on the health of occupants, both from a physical and psychological point of view. In schools, and due to the complex and diverse activities carried out, indoor air has a direct impact on students' performance. To improve IAQ one of the strategies is the use of plants, which have the ability to absorb indoor contaminants. This article shows the improvement in IAQ, through the analysis of the carbon dioxide and volatile organic compounds, using plants in an Eco-Campus classroom. Another line of investigation and taking into account the environmental sustainability of water efficiency on buildings and cities, is the analysis of plant growth through watering using treated wastewater (TWW). The results show a clear improvement in air quality through the installation of a natural green structure. Plant development seems not to be harmed using TWW for irrigation.

Keywords: Plants · Indoor Contaminants · Treated Wastewater

1 Introduction

Good air quality is a basic requirement for life, being a determining factor for the health and well-being of occupants in indoor spaces. The number of complaints related to indoor air quality has grown in recent years, mainly due to the increasing use of synthetic materials and current energy conservation measures in buildings.

Schools are one of the most important and critical infrastructures in society, one of the first places for social activities to develop, and one of the places where children and young people spend the most time indoors. Poor indoor air quality (IAQ) in schools,

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in addition to adverse health effects in the short and long term, can also affect the productivity, concentration and performance of the occupants of these spaces.

The Environmental Protection Agency (EPA) even suggests that poor indoor air quality can reduce occupants' ability to perform mental tasks that require concentration, calculation, or memorization.

There are several substances which contribute to a poor IAQ, among them carbon dioxide (CO_2) and volatile organic compounds (VOC), which represent several health hazards. Despite CO_2 is sometimes considered as non-toxic, high levels of CO_2 are associated with increased drowsiness, decreased cognitive ability, inflammation, and kidney and bone problems [1].

On the other hand, VOC exposure can have both short-term and long-term effects, and even at low concentrations, people with respiratory disorders, like asthmatics, are more vulnerable to its effects. At high levels, VOC can provoke symptoms like eye, nose and throat irritation, headaches, nausea, damage to liver, kidney, and central nervous system, among others [2].

Having these impacts in mind, its urgent to develop and implement strategies for improving IAQ, namely in schools where young people spend many hours, aiming to promote preventive health measures which will have short, medium, and long-term impacts, in public health and in health systems.

A good indoor air quality can be ensured through different actions, namely: cleaning or filtering the air and diluting pollutants in fresh air, through strengthening ventilation; removal or reduction of polluting sources [3]. Recently, the Italian Society of Environmental Medicine (SIMA) and the Chair on Health Education and Sustainable Development of the United Nations Educational, Scientific and Cultural Organization (UNESCO) presented a series of recommendations aimed to improve IAQ in schools. Among other measures, the use of plants as natural filters, capable of absorbing some indoor contaminants was proposed [4]. Furthermore, plants present visual comfort, promote stress reduction, providing psychological and physical well-being, enhancing productivity. Also, are associated with faster thinking, better attention, and higher cognitive development [5], being all this issues relevant in school's environment.

In the current study, the benefit of using plants to remove pollutants from indoor air in a real context, namely in university environments, was evaluated. Therefore, a natural green structure (NGS) was installed in an Eco-Campus classroom and the indoor air quality was compared with another classroom, without a NGS. It is expected that the application of the NGS inside the classroom will have benefits for IAQ, reducing CO_2 levels and eliminate significant amounts of VOC.

Also, taking into consideration questions regarding environmental sustainability and measures to promote circular economy policies, watering plants, adopting more sustainable strategies, was also a target in this study. Therefore, to adopt more efficient measures in the use of water, namely its reuse, treated wastewater (TWW) was used for watering some plants, instead of drinking water (DW). The use of TWW leads to a reduction in the use of DW, allowing a reduction in water treatment for human consumption, and consequently a reduction in water resources/treatments. Concomitantly the use of TWW promote the reduction of synthetic fertilizers, often used to promote plant growth, as

TWW contains various nutrient elements such as nitrogen (N) and phosphor (P) [6]. In the current project, plant growth is being monitored using periodic image analysis.

Sustainable Development Goals (SDGs) defined by the UN 2030 agenda currently play a crucial role in education, by providing a global framework to address a set of social, economic, and environmental challenges. The study under development envisages to integrate the SDGs in the educational curricula at ISEL, aiming to increase the community's awareness about environmental sustainability, how to achieve good health and well-being, how to promote clean water, contributing to sustainable cities and communities, with a responsible consumption.

The authors consider that education and research at Higher Education Institutions (HEI), aligned with the SDGs, are fundamental to promote innovation, contributing to the development and implementation of concrete solutions that promote resilient and healthier communities and promote green economy in a competitive and changing market.

2 Case Study

The present study aimed to evaluate IAQ, through monitoring several air quality parameters after installing a natural green structure (NGS) in a classroom at the Instituto Superior de Engenharia de Lisboa (ISEL). To carry out this study, two classrooms facing the southwest of the ISEL, located in Building G, with equal area, equal sun exposure, same number student's occupancy and identical glazing area, were chosen. Both classrooms present similar furniture, coatings, equipment, window frames, no air conditioning and door opening directly to an outdoor patio. These two classrooms were called as Neutral Room (NR – room without a natural green structure – plants) and Green Room (GR – room with a natural green structure – plants).

The selection of the type of plants to be integrated into the classroom with the NGS was made on the recognized absorption capacity of plants to absorb certain indoor pollutants, as explained in Miranda work [7, 8]. The NGS was installed on the opposite wall of the whiteboard, back of the classroom, and on the side walls of the GR, as can be seen in Fig. 1. The plants were divided into 2 different batches: 6 plants watered with TWW and 7 plants watered with DW, maintaining the same conditions of temperature, humidity and sun exposure. Plant growth was monitored through photographic recording with image analysis, comparing plants watered with TWW and watered with DW.

2.1 Indoor Air Quality Monitoring

IAQ monitoring took place in January 2024, which corresponds to the winter period in Portugal. Monitoring in both rooms was carried out simultaneously with the same number of occupants, between 1:50 pm and 4:30 pm. During monitoring period, the physical conditions of both classrooms were kept the same, with windows always closed, and the opening and closing of the doors carried out simultaneously in a controlled way.

To measure air quality, identical portable direct reading equipment were used in both classrooms. The equipment Kaiterra Sensedge Mini 5-in-1 was calibrated and placed in the center of the classrooms and the following parameters were monitored: CO_2, VOC_T, Particulate Matter 2.5 and 10 ($PM_{2.5}$, PM_{10}), Temperature (T) and Relative Humidity (RH). In this article, will be presented the results regarding CO_2 and VOC_T parameters.

Fig. 1. Green Room (GR) classroom under study.

2.2 Use of Treated Wastewater and Plant Growth Monitoring

This study was conducted in two stages. DW was used to irrigate all the NGS plants during the initial stage. In a second phase two groups of plants were created, from the same species and in similar environmental conditions, and colored flags were used to identify which plants received TWW and which received DW irrigation.

Plant growth was monitored through photographic recording and image analysis, using a free image analysis software. In order to reduce parallax errors in measurements, the photographic recording was always carried out in the same way, that is, with the plant always in the same position and with the camera always at the same distance, horizontal and vertical, from the plant.

3 Analysis and Discussion of Results

3.1 Indoor Air Quality Monitoring

The results obtained can be observed in Figs. 2 and 3. Observing the graphics it is possible to see a huge difference in values, both for CO_2 and VOC_T, with the GR presenting much lower values, when compared to the values in the NR.

It should be noted that, the two classrooms had exactly the same number of students (25 students in each room), the same infrastructure and sun exposure. Doors opening and closing was synchronized for both classrooms. The only difference between classrooms was the presence of the NGS in the green room.

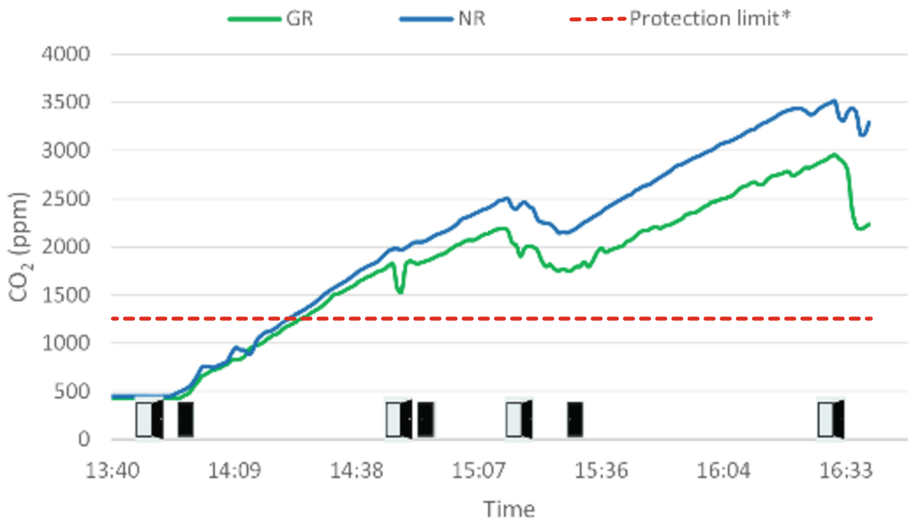

Fig. 2. Comparison of CO_2 levels between Green Room (GR) and Neutral Room (NR). *Ordinance nº 138-G/2021, 1st July.

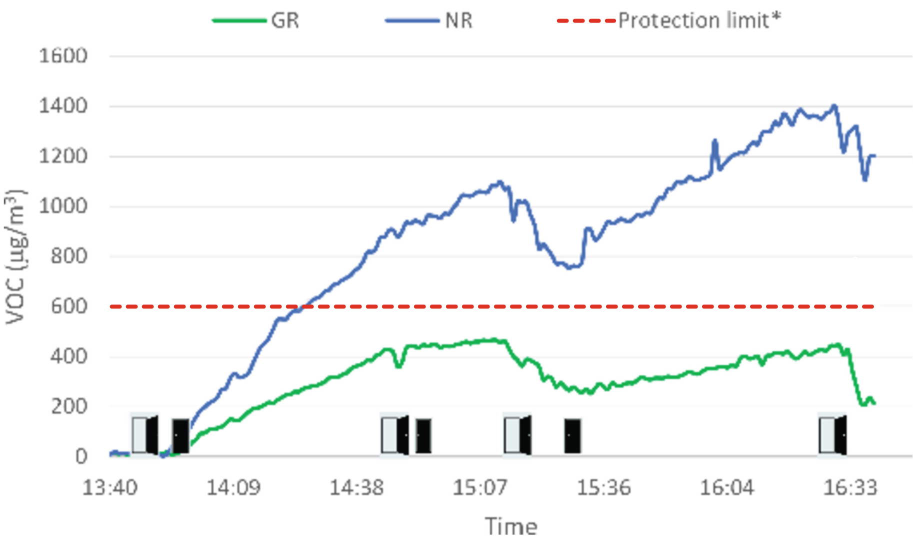

Fig. 3. Comparison of VOC_T levels between Green Room (GR) and Neutral Room (NR). *Ordinance nº 138-G/2021, 1st July.

Observing the values for CO_2 (Fig. 2) it can be stated that the values achieved are significantly lower in the GR than in the NR. This decreases it's probably due to plant photosynthesis process, which leads to the absorption of CO_2 and release of O_2, during daylight. However, in both classrooms CO_2 levels surpassed the protection threshold imposed by Portuguese ordinance legislation nº 138-G/2021 (1250 ppm).

The values obtained for the VOC_T are even more disparate, with a significant difference being observed between the two classrooms. It can be seen (Fig. 3), that GR presents VOC_T values below the limits imposed by Portuguese legislation (600 mg/m^3), and in the NR these values are strongly exceeded, and are in non-compliance with the protection thresholds defined in the Portuguese ordinance legislation nº 138-G/2021.

For example, it can be observed at 4:30 pm in the GR that the VOC_T values are around 440 mg/m^3 (value below the imposed limits) and in the NR the values are around 1400 mg/m^3 (value far above the imposed limits). It is also observed that the values monitored decreased drastically when the door is held open for a period of time. It should be noted, as previously mentioned, that rooms doors open directly to an outside patio. And outside of buildings, CO_2 and VOC_T concentrations are lower than those within.

VOCs are emitted by a wide array of products, like paints, varnishes, wax, cleaning products, aerosol sprays, air fresheners, building materials, furnishings, office equipment, glues, cosmetics, among others. However, in this study both rooms were cleaned equally, several hours before the monitoring, and the building materials and furnishings are old enough to have a reduced emission of COV.

With that in mind it can be considered that in the classrooms monitored, the occupants were the primary source of CO_2 and VOC, as also considered in other studies [9] and the impact of the NGS is clearly evidenced.

With this monitoring, the importance of adequate ventilation to obtain a better IAQ was also verified. When the door opens for more than 15 min, such as in the period between 3:12 pm (door opening) and 3:30 pm (door closing), there was a clear decrease in CO_2 and VOC_T values (Figs. 2 and 3) due to natural ventilation. On the other hand, when the door and windows are closed, there was a sharp increase in values, both in CO_2 and in VOC_T.

3.2 Use of Treated Wastewater and Plant Growth Monitoring

After the start of irrigation with TWW, similar growth was observed in all plants. No damage or diseases were observed in plants irrigated with DW or in those irrigated with TWW, as can be observed in Fig. 4. The monitoring made so far, shows that irrigation with TWW is an interesting water efficiency measure to adopt, with no disadvantages for the plants, compared to the use of DW.

The plant growth monitoring data is undergoing, with some preliminary results obtained [10] and the final results will be presented in a future publication.

4 Conclusions

The results obtained show that there is clear evidence of improved IAQ with the presence of a natural green structure. This evidence becomes more advantageous for the VOC_T parameter, leaving it below the protection limit imposed by Portuguese legislation. Even when CO_2 concentration exceeds the protection limit, the results show that the presence of plants help to reduce this pollutant. Another relevant observation is about the importance of natural ventilation which clearly improves IAQ. The monitoring data

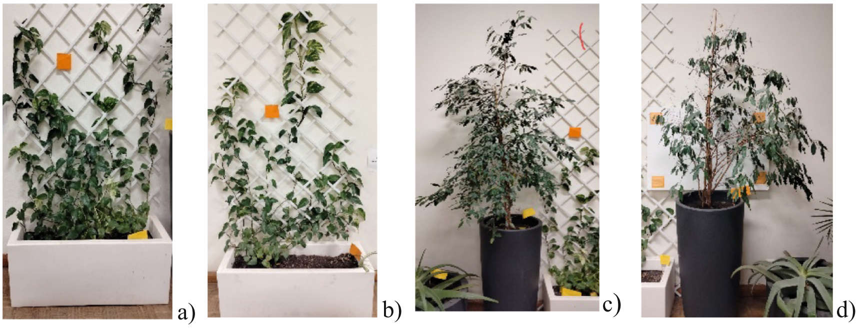

Fig. 4. Plants watered with: DW a) and c); TWW b) and d).

unequivocally corroborate certain authors' claims that QAI is improved by the presence of a NGS [11–14].

Based on the plant observation, it can be concluded that using TWW instead of DW for plant watering is an effective way to increase the water and energy efficiency of institutions.

In addition to the IAQ improvement, as mentioned previously, some studies published in the field of psychology and mental health have shown that, plants also present several advantages in terms of performance, cognitive capacity, stress reduction and well-being of the occupants. This aspect is particularly important, as statistics have recently been released indicating that young people who attend higher education in Portugal suffer from high levels of stress and frequently display symptoms of depression. In the current project this aspect is also being assessed [8] and final results will be published shortly.

The health and well-being of people and the planet are central issues to the 17 Sustainable Development Goals (SDGs). The current study aims to inprove IAQ and water efficiency in buildings, aspects that cross multiple SDGs, promoting the scholar population's health and well-being (SDG 3), increasing water efficiency (SDG 6) due to the use of TWW for water plants, and improving buildings IAQ (SDG 11 and 12).

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Energy to Water *Nexus* in Wastewater Treatment Plants

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Abstract. WWTPs require energy for various processes such as pumping, aeration, mixing, and biosolids treatment. The energy is mainly used for moving water through the treatment process and providing aeration to promote the growth of microorganisms that break down organic pollutants. The main aim of this paper was to analyze energy consumption in three wastewater treatment plants, with the same treatment process, in accordance with the treated flow, and try to find a relation between these two essential resources, in order to propose improvement measures of manage these systems.

As expected, generally, the periods of highest flow of wastewater in the WWTP correspond to energy highest consumption. In this case the KPI (kWh/m3) increased with the volume of treated flow. The energy produced represents a small amount compared to what is needed to the WWTP operation. As expected, the most part of energy consumption is related to biological treatment.

By understanding and optimizing the energy-to-water nexus, WWTPs can improve their environmental performance, reduce operational costs, and contribute to a more sustainable water management system.

Keywords: Energy Consumption · Treated Flow · WWTP's

1 Introduction

The energy-to-water nexus in the urban water cycle refers to the interdependency between water and energy systems within urban environments. This nexus encompasses various aspects, including the energy required for water extraction, treatment, distribution, and wastewater treatment, as well as the water needed for energy production and cooling processes. Understanding and optimizing this relationship is crucial for sustainable urban development.

In fact, energy is required at every stage of the water supply process, from pumping water from its source (e.g., rivers, lakes, groundwater) to treating it to meet drinking water standards. Technologies such as pumps, filtration systems, and chemical treatment

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processes all consume energy. Moreover, transporting water through pipelines to urban areas requires energy for pumping. The efficiency of these pumps and the design of the distribution network can significantly impact energy consumption. Similarly, collecting and treating wastewater involves energy-intensive processes such as pumping, aeration, and biological treatment [1]. Energy-efficient wastewater treatment technologies and decentralized treatment systems can reduce energy consumption [2].

Ramos et al., (2010) [3] refer that, according to the characteristic load curves for water and energy consumption, the periods of highest consumption of water and energy occur at about the same time.

The energy-to-water nexus in wastewater treatment plants (WWTPs) is a critical aspect of urban water management. Here's a breakdown of how energy and water intersect within WWTPs [4]:

1. Energy for Treatment Processes: Wastewater treatment involves multiple energy-intensive processes such as aeration, mixing, and pumping. Aeration, particularly in activated sludge systems, is one of the most energy-consuming processes. It involves pumping air into the wastewater to promote microbial degradation of organic pollutants. Other processes like pumping water within the plant and mixing in tanks also require energy.
2. Energy Recovery: While WWTPs consume significant amounts of energy, there's also potential for energy recovery within these facilities. Anaerobic digestion of sewage sludge, for example, can produce biogas (mostly methane), which can be used as a renewable energy source for heating, electricity generation, or even as a vehicle fuel. Combined Heat and Power (CHP) systems can efficiently utilize biogas for both electricity and heat production.
3. Water Reuse Opportunities: Some WWTPs incorporate water reuse schemes, where treated wastewater (effluent) is recycled for non-potable uses such as irrigation, industrial processes, or toilet flushing. Implementing water reuse reduces the demand for freshwater resources and can alleviate pressure on water supply systems. However, depending on the treatment level required for reuse, additional energy may be needed for advanced treatment processes.
4. Energy-Efficient Technologies: WWTPs can implement various energy-efficient technologies and practices to reduce their overall energy consumption. These may include optimizing aeration systems, using energy-efficient pumps and motors, employing advanced control systems for process optimization, and incorporating renewable energy sources onsite, such as solar panels or wind turbines.
5. Energy and Water Quality Trade-offs: Balancing energy efficiency with water quality standards is essential in WWTP operation. For instance, reducing aeration to save energy may compromise treatment efficiency and water quality. Therefore, operators must carefully optimize processes to achieve both energy savings and water quality goals.

Overall, the energy-to-water nexus in WWTPs underscores the importance of integrated approaches that optimize energy and water use, maximize resource recovery, and minimize environmental impacts throughout the wastewater treatment process. Efficient and sustainable management of this nexus is essential for building resilient and environmentally responsible urban water systems [5, 6].

Addressing the energy-to-water nexus requires integrated planning and management approaches that consider the synergies and trade-offs between water and energy systems [7]. This includes optimizing infrastructure design, promoting water and energy efficiency, and fostering collaboration among stakeholders. By recognizing and addressing the complex interactions between water and energy systems, cities can enhance their resilience, reduce resource consumption, and move towards more sustainable urban development.

The main aim of this paper is to present three different wastewater treatment plants and analyze their' s energy consumption in accordance with the treated flow, and try to find a relation between these two essential resources, in order to propose improvement measures of manage these systems.

2 Methodology

Three wastewater treatment plants from the north of Portugal were chosen, in order to characterize the energy consumption during the wastewater treatment, and try to find a relation between the energy consumed and the treated flow.

For all the treatment plants data of energy consumption and treated flow was collected during nine months (between May, 2017 and January, 2018) in each one of the three treatment plants. The design of all three WWTP's had the same treatment process and effluent standard. The third key design parameter (Scale) was the one that was different and it may be confirmed by the values of flow treated in each WWTP.

It was possible to calculate one of the energy key performance indicators (KPIs) as follows:

$$kWh/m^3 = \frac{Energy\ Consumption}{Volume\ of\ Treated\ Wastewater}$$

In one of the treatment plants (3), there is energy production from anaerobic digestion and so it was possible to collect data from the energy saving achieved. Moreover, in this WWTP it was possible to scrutinize how much of the total energy is spend in the biological treatment.

3 Results and Discussion

In Fig. 1 are presented the results of treated flow and energy consumption in WWTP 1, between May, 2017 and January, 2018.

In Fig. 2 are presented the results of treated flow and energy consumption in WWTP 2, between May, 2017 and January, 2018.

In Fig. 3 are presented the results of treated flow and energy consumption in WWTP 3, between May, 2017 and January, 2018.

According to the presented curves for wastewater treated flow and energy consumption, generally, the periods of highest flow of wastewater in the WWTP correspond to energy highest consumption. This came in accordance with what was stated by [3] in relation to the periods of highest consumption of water and energy in characteristic load

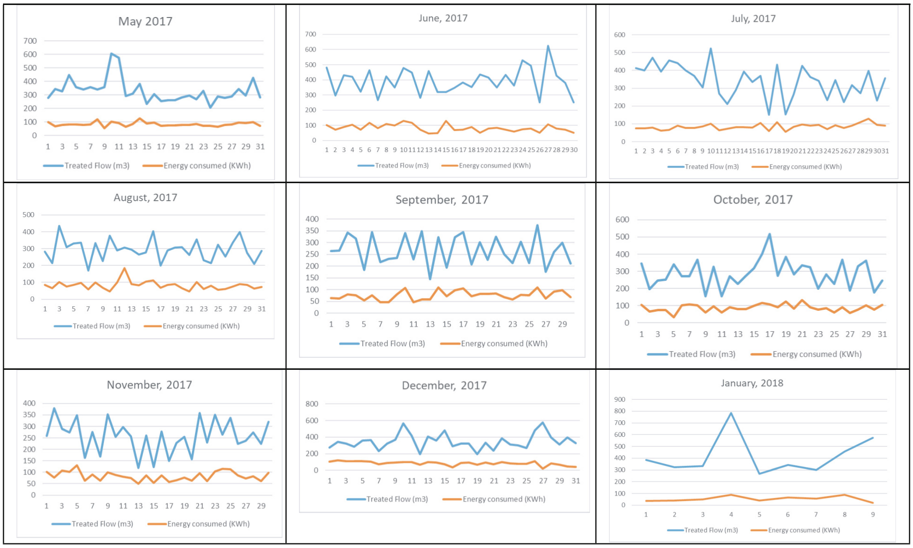

Fig. 1. Treated flow (m^3) and energy consumption (KWh) in WWTP 1.

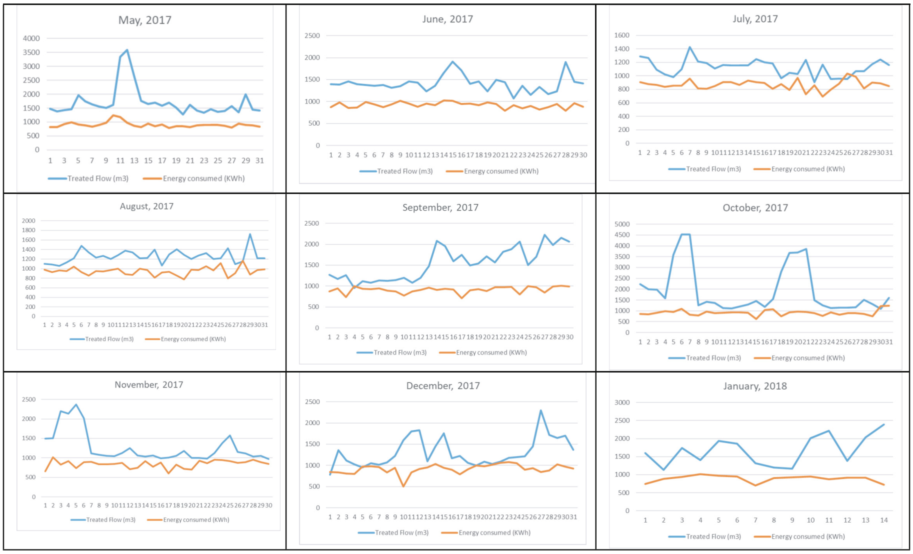

Fig. 2. Treated flow (m^3) and energy consumption (KWh) in WWTP 2.

curves that occur at about the same time. This behavior is not so evident in Fig. 3, once there is energy production in the treatment plant. In fact, although sludge itself contains potential energy, by self-generated electricity from sludge, sludge treatment also consumes considerable energy, by the anaerobic digestion (usually for heating) and sludge

Fig. 3. Treated flow (m^3) and energy consumption (KWh) in WWTP 3.

dewatering (belt press etc.) [8]. Taken together, the minimization of energy consumption can be achieved by optimizing the design and layout of WWTPs including aeration equipment, pump and sludge treatment as well as intensifying self-generated energy [9].

By the observation of the results it is possible to conclude that in this case the KPI (kWh/m^3) increases with the volume of treated flow. These results aren't in agreement with the ones found by Trapote et al., (2013) [10]. In their study the energy consumption ratio increased as the size of WWTPs decreased, and that there were similar functional relationships between the ratio of energy consumption and the size of the WWTP, expressed in volume of treated wastewater. According to He et al., (2019) [9], generally, the unit energy consumption presented a decreasing trend with the increased scale of WWTPs. However, the downward trend of unit energy consumption reversed with WWTPs scale beyond 50×10^4 m^3/d. In this study the average of unit energy consumption of the five levels of scale (<5 x 10^4 m^3/d; 5–10 m^3/d; 10–20 m^3/d; 20–50 m^3/d; > 50 m^3/d) was 0.330 kWh/m^3, 0.256 kWh/m^3, 0.254 kWh/m^3, 0.249 kWh/m^3 and 0.308 kWh/m^3, respectively. Our results showed higher levels of energy consumption, what may indicate excessive electrical energy lost in moving wastewater around super-large scale WWTPs due to friction in the channels and pipes or other types of inefficiency that need to be addressed.

The present work lacks of consolidated evaluation of energy consumption of WWTPs, once it only considered a single parameter, that was treated flow and there are other parameters that could help to explain these results. The previous studies also have considered a single parameter, e.g. treatment scale, [4, 10], treatment process [11, 12], operation units [5], organic load [13], as well as partial combination of these parameters [14–16]. Few energy consumption assessments have been done in combination with effluent standard and regional distribution. These is undoubtably a consideration for future work.

As a matter of fact, effluent standard is closely linked to WWTPs energy consumption, once it will define the pollutant load that needs to be removed [9], and this was a key design parameter that was not evaluated in the present paper.

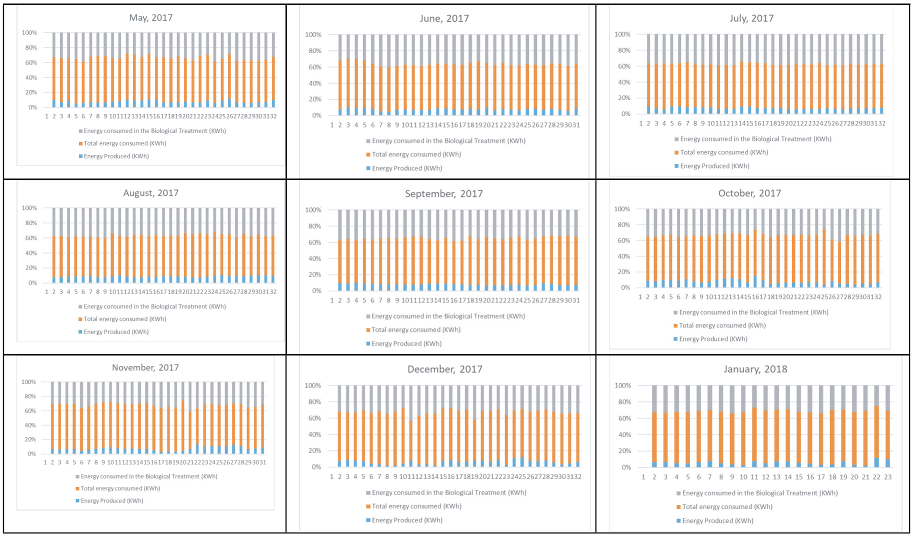

Fig. 4. Energy produced, total energy consumed and energy consumed in the biological treatment. in WWTP 3.

The energy produced represents a small amount compared to what is needed to the WWTP operation. As expected, as it may be seen in Fig. 4 and Table 2 the most part of energy consumption is related to biological treatment. As a whole, the biological treatment constitutes the major part of the overall energy consumed in WWTPs. The most energy-demanding unit is the use of electricity to provide oxygen for aerobic system [9]. Such kind of energy consumption depends on influent loading, effluent quality, aerator type, treatment process and size of WWTPs [5]. In the present study the value of energy consumption varies between 49 and 67% of the total amount of energy consumed in WWTP 3.

4 Conclusions and Final Remarks

Faced with the rising pressure of high energy costs, environmental engineers and policy makers have to rethink the traditional design principles and adjust basic design parameters of WWTPs in energy saving direction. The proper selection of energy consumption indicator is the requirement step for energy assessment system. Although this study used the most common indicator (electricity consumption per volume of wastewater treated) for analyzing energy consumption, it had some limitations such as ensuring similar influent quality of all WWTPs.

Table 1. Treated flow, energy consumption and KWh/m^3 values for all the three WWTP.

	WWTP 1			WWTP 2			WWTP 3		
	Treated Flow (m3)	Energy Cons. (KWh)	KWh/m3	Treated Flow (m3)	Energy Cons (KWh)	KWh/m3	Treated Flow (m3)	Energy Cons. (KWh)	KWh/m3
May, 2017	10213	2572	0,25	52947	28006	0,53	130348	118396	0,91
June, 2017	11788	2466	0,21	42280	27520	0,65	120979	105807	0,87
July, 2017	10548	2619	0,25	34888	26913	0,77	112888	81994	0,73
August, 2017	9098	2563	0,28	39041	29323	0,75	108118	116715	1,08
September, 2017	8017	2276	0,28	46302	27324	0,59	99355	105292	1,06
October, 2017	8921	2712	0,30	60258	28393	0,47	112696	62927	0,56
November, 2017	7715	2505	0,32	38125	25224	0,66	112499	112945	1,00
December, 2017	10773	2620	0,24	40567	28438	0,70	140364	106801	0,76
January, 2018	3761	488	0,13	23390	12428	0,53	115229	81305	0,71
Mean	8981,56	2313,44	**0,25**	41977,56	25952,11	**0,63**	116941,78	99131,33	**0,85**
Std	2368,06	695,43	0,06	10574,20	5201,13	0,10	12190,73	19152,98	0,18

Table 2. Percentage of the total energy consumed, used in the biological treatment (WWTP 3).

Month	(%)
May, 2017	57
June, 2017	64
July, 2017	67
August, 2017	67
September, 2017	61
October, 2017	57
November, 2017	53
December, 2017	54
January, 2018	49

However, some conclusions came out of this study. As expected, generally, the periods of highest flow of wastewater in the WWTP correspond to energy highest consumption. The KPI (kWh/m3) increased with the volume of treated flow.

The collection of data related to energy production allowed to consider that the energy produced represents a small amount compared to what is needed to the WWTP operation. As expected, the most part of energy consumption is related to biological treatment.

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Identification of Influencing Factors of Energy and Water Consumption at the Residential End-use Level

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Abstract. Understanding and addressing the complex interactions between energy and wa-ter resources are essential to guarantee the sustainable development and resilience required to face the growing demands and climate change impacts. Integrated planning and management approaches that consider both energy and water sec-tors are crucial for optimizing resource use and minimizing environmental im-pacts. In fact, the achievement of domestic demand management plans depends on the identification of the factors influencing the water and energy consumption and their interaction in different environments.

Determinants of energy and water usage can vary widely depending on factors such as geographical location, socioeconomic conditions, technological advancements, and policy frameworks, among others. By incorporating the various influencing factors, it is intended with this study to explore the underlying determi-nants of household water and energy consumption at the residential end-use level.

Understanding these determinants and their interactions is crucial for the devel-opment of effective strategies to manage energy and water resources sustainably, promote efficiency, and address challenges such as water scarcity, climate change, and environmental degradation.

Keywords: Water-Energy Nexus · Influencing Factors · Residential

1 Introduction

It is well known that energy and water are two important resources for human living, whose security has become a priority at the regional, national and global scale. A sustainable supply of energy and water resources plays a key role in the economic health, given their closed interconnection [1]. In fact, water and energy are integrated systems and the link that can be established between these two resources is called the 'water-energy nexus' [2]. The relevance of water-energy nexus is shown by the fact that water distribution requires enormous amounts of energy and energy production equally requires large

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amounts of water [3]. Indeed, energy plays an important role in water supply. According to Stillwell et al. (2011), half of a city's energy demand is due to water supply and wastewater treatment processes [4].

The development and implementation of any water and energy conserving methods requires to identifying and understanding the related factors toward water and energy consumptions from the beginning [5]. The need for an integrated analysis is a global concern. However, the high changeability in fresh water distribution and its use cycle involves indeed an assessment to detect the influencing factors and to identify the most appropriate policy directions and technologies. The balance of water supply and energy is affected by a wide variety of aspects, including social factors, technical growth and climate uncertainties [6, 7]. Investigation carried ou in this field has confirmed, through various empirically based studies, that there are several factors affecting residential energy and water consumption. Most of the studies focus on electricity consumption [8, 9]. In an analogous way, few articles discuss aspects affecting the energy consumption for space and water heating from a statistical point of view [10, 11]. Furthermore, investigation already developed in the field revealed that more research should be conducted to better characterize the water-energy nexus concept at different scales.

By incorporating the various influencing factors, it is intended with this study identifying determinant influencing factors of water and energy consumption at the residential end-use level.

2 Influencing Factors of Energy and Water Consumptions at the Residential End Use Level

The achievement of domestic demand management plans depends on the identification of the factors influencing the consumption of water and energy and their interaction in different environments [12]. The knowledge of these differences may turn conceivable the estimation of the household consumptions, what is fundamental to perform efficient and effective supply and demand balance assessment at household level. Gutierrez-Escolar, A. et al. (2014) performed a detailed study of the factors that influence or may influence energy consumption, whose analysis is presented in Table 1 [13]. The author analyzed four studies carried out in this area and concluded that there is no agreement regarding the factors that may influence water and energy consumption. The leading factors that appear in the most part of the studies refers to the type of building, the flow rate, the domestic hot water temperature, the heat tank losses, the time of year and the occupancy, among others.

In the next sections, the most important factors that may lead to better understand the closed relation of water and energy consumption will be highlighted and discussed.

2.1 Socio-Economic and Socio-Demographic Factors

Several studies in this are focused on evaluating the dynamic impacts of energy-water policies. However, some research also assesses the dynamic effects of socio-economic factors at regional and city levels, including urban size [18], population density [19], domestic occupation [20], international trade [21], and adjustments in industrial structure

Table 1. Factors studied in each research (adapted from Gutierrez-Escolar, A. et al., 2014).

Analyzed factors	Ndoye [14]	Bouchelle [15]	Aydinalp [16]	Yao [17]
Building type	+	+	+	+
Flow rate (L/in)	+	–	+	–
Regional climate	–	–	–	+
DHW temperature	+	+	+	+
Heat tank losses	+	+	+	–
Time of the year	–	+	–	+
Solar water heaters	–	+	–	–
Pipe insulation	–	–	–	–
Occupancy	–	+	–	+
Household income	–	–	+	–
Dwelling ownership	–	–	+	–
Area of residence	–	–	+	–
Energy sources	–	–	+	–
Number of water heaters	–	–	+	–
Age of system	–	–	+	–
Size of the water tank	–	–	+	–

“ +”: applicable factor; “–”: not applicable factor

[22]. Additionally, current studies often address the nexus of urban sectors from a static perspective [18, 23, 24].

Several socio-demographic factors can influence water and consequently energy consumption. The ARCWIS (2002) study on socio-demographic variables found that owner-occupied properties, higher-income families, and households with swimming pools consumed more water for irrigation [25]. Additionally, the occupancy and character of dwellings, lot size, and the age of water devices also directly impact water consumption [26]. Loh and Coghlan (2003) reported a strong association between income level and outdoor water use [27].

Makki et al. (2015) investigated the primary factors influencing six categories of residential indoor water use at the household level: clothes washer, shower, toilet, tap, dishwasher, and bath. The study revealed that physical usage characteristics, along with demographic and household composition, are crucial determinants across all six water use categories. Moreover, the physical attributes of appliances and fixtures were key determinants for all categories except for the bath. Socio-demographic factors were also influential for all categories except the tap and toilet. The findings indicated that the primary drivers of higher water consumption in these categories were households with more frequent and/or prolonged usage events, typically larger families with teenagers and children, higher income levels, primarily employed residents, and/or higher educational attainment [28].

Fernando Arbués et al. (2002) showed that families with children tend to spend more water. According to the author, young people tend to use water less carefully, often unconsciously, while older people tend to be more frugal [29]. Kim et al. (2007) and Plappally et al. (2012), also concluded that water consumption increased with the presence of children [30, 31]. Berk et al. (1993) found that households with children are more likely to engage in water conservation practices [32]. Nauges and Thomas (2000) reported that water consumption tends to be higher in areas with a larger proportion of younger individuals due to more frequent laundering and the use of water-intensive outdoor leisure activities. Conversely, communities with a higher proportion of older residents may place greater emphasis on gardening [33].

Willis et al. (2009) studied the influence of socio-economic factors and the adoption of efficient devices on the end-use of water on the Gold Coast, Australia. Data were acquired over a two-week period during the winter of 2008 when there were no residential water restrictions. This study of end-use water consumption, including a questionnaire, was carried out simultaneously for 151 households on the Gold Coast. The authors concluded that the higher the income of the occupants, the greater the water consumption. It was also identified a general decrease in per capita consumption in the case of large families [34]. Millock and Nauges (2010) also discovered a significant and positive correlation between household size and the adoption of water-saving technologies [35].

While it is generally expected that water demand rises with income, assessing this relationship is challenging due to the interconnectedness of income with educational attainment (which influences water conservation practices) and the consumption of water-intensive luxury goods [36]. Berk et al. (1993) found that higher income levels are associated with increased adoption of water conservation measures [32]. In contrast, De Oliver (1999) reported that households practicing water conservation tend to have lower income levels [37]. Sütterlin et al. (2011) reached the same conclusions regarding energy saving habits [38].

Yu et al. (2011) conducted an extensive analysis of end-user spending, both on and off the property, using data from a 2009 study in Beijing, China, involving more than 1000 families. They concluded that factors not previously studied, such as social, cultural, psychological, and life factors, play a much more important role in explaining energy consumption behavior. However, according to the survey, larger families consume less energy, whereas families with higher incomes spend more energy [39].

Keshavarzi et al. (2006), investigating rural domestic water consumption pattern showed that household size and age of the household head affect per capita water consumption. This investigation found a negative relationship between the household head's education and water consumption [40].

Contrary to Lam's (2006) conclusion that formal education does not influence the intention of water conservation [41], Martínez-Espiñeira and García-Valiñas (2013) found that lower levels of formal education negatively correlate with the use of water-efficient technologies. They also found a negative correlation between income levels and water-saving behavioral patterns [42].

2.2 Building Characteristics

Keshavarzi et al. (2006) found that water consumption depends on the size of the household, housing quality, water use patterns, water supply system, and its maintenance [40].

Research was carried out by Arpke et al. (2006) regarding the impact of building characteristics on water and energy consumption. This study considered the water supply network and the perception of its route. Water travels through a municipal distribution system, passes through a main building, and reaches the housing buildings. Depending on the available pressure, the water is fed through the building's pipe system, where it is divided into two branches: one towards the water heating device and the other toward the cold-water supply devices. The study examined four different types of buildings: a 30-unit apartment building (78 occupants), an 18-room motel (maximum 24 occupants), a 400-student dormitory, and a 415-occupant office building. It was concluded that 93 to 97% of the energy consumed corresponds to the heating of water in the buildings [43].

2.3 Behavioral Factors

Within the behavioral factors, there are several sub-factors that influence the behavior of the occupants, particularly at the psychological level [44]. The quest to reduce water and energy consumption by changing end-user behavior has gained increased research attention [45].

Aitken et al. (1994) found that individuals who received dissonance and feedback, or feedback alone, significantly reduced their water consumption. Attitudes, subjective norms, and perceived behavioral control are associated with relevant sets of behavioral, normative, and control beliefs about the behavior. However, uncertainties remain regarding the precise nature of these relationships [45]. Furthermore, it was also stated that expectancy-value formulations are only partly successful in dealing with these relations [46]. Findings also indicate that households with lower water consumption demonstrate a higher awareness of water conservation issues. These households are more engaged in water use decisions and tend to adopt habits that align with reduced water usage levels [48].

Water conservation campaigns are widely utilized to encourage household water-saving practices. However, despite their prevalence, there is ongoing debate regarding their effectiveness [49].

Sarabia-Sanchez et al. (2014) discovered that individuals with a pro-sustainability orientation are more inclined to undertake actions that may conflict with their short-term interests in the context of water conservation. Their study highlighted that there is a distinction between perceived efficacy and actual efficacy of conservation behaviors, and that involvement plays a critical role in predicting perceived water conservation efforts [50].

Yildirim and Semiz (2019) investigated how environmental awareness affects water consumption. Their findings indicated that norms mediate the relationship between the sense of responsibility and the adoption of sustainable water consumption practices. Furthermore, the sense of responsibility serves as a mediator between awareness of consequences and personal norms. They also discovered that awareness of consequences mediates the link between biospheric-altruistic values and the sense of responsibility. Finally, personal norms mediate the connection between biospheric-altruistic values and sustainable water consumption behaviors [51].

The study further highlighted that attitudes, norms, and habits are crucial in shaping the intention of conserving water, with habits emerging as the most significant predictor of water conservation intentions and self-reported water bills [52].

2.4 Urbanization

Venkatesh et al. (2014) investigated the impact of the urban environment on the water-energy-carbon nexus through four case studies in Nantes (France), Oslo (Norway), Turin (Italy), and Toronto (Canada). The study highlighted that climate, technology, and geography significantly influence the water-energy-carbon nexus across various regions. The authors provided recommendations for process, program, and policy interventions aimed at addressing these influences [53].

Keshavarzi et al. (2006) found that domestic water consumption varies significantly based on consumer lifestyle and whether they reside in urban or rural areas. The study indicated that water consumption depends on household size, water usage patterns, the water supply system and its maintenance, family members' education, and ages. Socio-economic factors like housing quality also influence water consumption. The study concluded that in rural areas, household size and the age of the household head impact per capita water consumption [41].

Chen and Lu (2015) pointed out that socio-economic factors, such as economic growth and urbanization, have been integrated into the urban nexus paradigm. Numerous studies have assessed how these intertwined factors influence urban development from a nexus perspective [54].

Research confirms a substantial difference in water consumption patterns between urban and rural households, though rural household consumption is less studied compared to urban residential consumption [55]. Rural households use water (and consequently energy) for both indoor and outdoor processes. Sandiford et al. (1990) examined the impact of distance from the water source on domestic water consumption in rural areas of developing countries [55]. Hunnings (1996) presented that the quantity of water used depended on the number of people in the household, the level of maintenance of the water supply system, and other factors such as education level and the age of the household head. In Israel, Martin (1999) found that the increase in domestic water use could be better explained statistically by household growth rather than population growth [56].

Krey, V. et al. (2012) conducted a dynamic analysis of potential future developments using dynamic models (integrated evaluation models—IAMs). The study compared structures, data sources, and scenario results from four integrated assessment models (GCAM, IMAGE, iPETS and MESSAGE), each capable of analyzing different aspects of urbanization. These models, developed for varied purposes, differ in their structural characteristics related to the incorporation of urbanization and have different strengths in representing urbanization impacts. The study emphasized the distinctions between urban and rural areas, underscoring the critical role of urbanization in economic development, environmental impact, and human well-being, especially in developing countries. It noted that urban and rural areas differ significantly in their economic structures and income levels, as well as in household behaviors and resource utilization. Additionally, exposure to indoor air pollution from traditional fuel use varies between these areas. Other notable differences include variations in activity sectors and income effects, which impact consumption patterns [57].

2.5 Geographic Location and Climate Factors

Plappally (2012) found that energy consumed in the residential sector largely depends on geographic location and climate, as is the case in Australia. In cities where average annual temperatures are highest (Birsbane and Gold Coast), there is less energy consumption. They noted that energy consumption at the household level is closely linked to behavioral and cultural factors [31].

Gutierrez-Escolar et al. (2014) studied domestic hot water (DHW) consumption in dwellings within regions with different climates. They concluded that in the northern regions, which tend to be colder, they have a higher average of energy consumption, while in the southern regions, which have a Mediterranean climate and more pleasant temperatures, the average energy consumption is lower [13].

According to Worthington and Hoffman (2008), residential water use is highly sensitive to seasonal fluctuations. Weather and other seasonal factors have been specified in various ways: temperature, minutes of sunshine, precipitation, rainfall, temperature and rainfall, the number of rainy days, among others [36].

Martinez-Espinera (2002) suggested that the occurrence of rain has a psychological impact, with the number of rainy days having a greater impact on water demand than the amount of rainfall [58].

Fernqvist and Hansla (2021) found that people living in cold climate cities, particularly renters with fresh water included in their rent, often do not perceive fresh water as a limited resource, despite its capital and energy-intensive treatment and distribution [44].

3 Conclusions

The interconnection between energy and water is fundamental, as both resources are crucial to human existence and their secure supply is essential at regional, national, and global levels. The concept of the energy-water nexus underscores their significant interdependence and highlights the need for understanding various factors influencing residential water and energy consumption, which includes socio-economic and socio-demographic factors, building characteristics, behavioral patterns, urbanization, and geographic location and climate factors. Addressing these influencing factors through policy interventions, technological advancements, and behavioral changes can help promoting energy and water conservation at the residential end-use level.

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Water Efficiency Perception Among Higher Education Students

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Abstract. The present study surveyed students from 7 High Education Institutions (HEI) in Portugal aiming at analyzing university students' perceptions regarding water efficiency. A questionnaire answered by 663 students revealed that they are very aware of the importance of water resources, strongly agreeing that water is essential for the livelihood and health of the environment (73%) and essential for human activities (71%). When asked to rank measure to increase water efficiency, "Reducing leaks and water waste" and "Reduce consumption" were ranked 1st by 39% and 38% of respondents, respectively, while the "Use alternative sources of water" was ranked 4th by 70% of respondents. Students also identified relevant Sustainable Development Goals that are positively affected by adequate water efficiency. The main sources of information identified regarding water efficiency are "Social communication", "Internet and social media" and "Family background", revealing the relevance of not only present communication channels but also the importance of intergenerational knowledge passing.

Keywords: higher education · Sustainable Development Goals · water efficiency

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1 Introduction

The sustainability and continuity of actions are strongly encouraged by the UN 2030 Agenda and its implementation across governments, policies and educational frameworks [1]. Nonetheless, it is crucial to recognize that most of the efforts made by higher education institutions will not lead to the desired results without a significant understanding of the importance of sustainability and its implementation in everyday life [2], and Sustainable Development Goals (SDG) 6 and 12 related to water resources are not an exception.

The excessive use of water is a critical issue as it is a mismanaged and virtually finite natural resource.

To effectively communicate information about water efficiency to the public and foster behavioral change, it is essential to understand the current attitudes of higher education students toward this issue. By gaining insights into these attitudes, we can develop more targeted strategies to raise awareness and empower individuals to adopt water-saving habits, including strategies such as the use of water-efficient appliances. In reality, good water governance involves, among other things, improved efficiencies and good practice in the use of water [3].

Without knowledge it is impossible to manage and so, becoming aware of the amount of water that each person uses, whether directly or indirectly, allows people to be more responsible and helps to make more sustainable choices.

The conservation of natural resources has become a global concern, raising awareness among people who may not have previously recognized the importance of water conservation. This increased awareness helps individuals understand how water scarcity could directly or indirectly impact their lives [4].Understanding how individuals and groups are likely to respond to the threat of water scarcity is crucial for designing educational curricula, marketing campaigns, and effective conservation strategies [5].

There are some demographics characteristics, such as age, education, gender and political orientation [6–8] that have been shown to influence environmental awareness and conservation. However, in these studies [9–11], the mean age of respondents to these surveys was above 40 years. There is limited formal research on university students' perceptions, intentions, and behaviors concerning water conservation. The study by Barreiros et al. [12] offered valuable insights into water consumption and the water management strategies implemented at higher education institutions (HEIs) in Portugal. This study identified best practices such as monitoring water usage, installing water-saving devices on taps, and conducting awareness campaigns. However, the adoption of good water practices by HEIs does not necessarily ensure that students are aware of or understand these initiatives.

The purpose of this study aims to fill that gap by analysing university students' perceptions about water resource usage, their personal levels of active engagement in water conservation, namely related to the importance of water resources, the efficient water management, the sources of knowledge regarding water efficiency measures and contributions of water efficiency to SDG.

2 Methodology

The data were collected through a questionnaire created by the Working Group on Efficient Use of Water, of the Portuguese Sustainable Campus Network. The questionnaire had received prior approval from an Ethics Committee and the Higher Education Institutions that participated in the study. It was conducted online via EUSurvey between May and October 2023. The invitation to participate in the study was sent via email to students from seven Portuguese HEIs.

The survey gathered responses from students across various fields and study levels. Regarding statistical validity, it is imperative that the sample size be reflective of the overall student population, which in 2023 numbered 45,142. According to Cochran's modified formula for finite populations [13], the resulting sample size of 663 has a 99% confidence level and a maximum margin of error of 5%, which is deemed to be an adequate and representative sample.

Four questions from the questionnaire were analysed to understand the students' overall perception of the relevance of water management and the source of information:

- Importance of water resources;
- Efficient water management;
- Sources of knowledge regarding after efficiency measures;
- Link to SDG.

A statistical analysis was performed using SPSS software. The influence of age, gender and study area on perceptions of water resources was analysed using non-parametric tests, following the determination of the absence of normality through Kolmororov-Smirnov and Shapiro-Wilk testing. The level of significance was set at $p = 0.05$.

The relationship between water efficiency and Sustainable Development Goal (SDG) is explored through a simplified network analysis, employing the Gephi software (version 0.1).

3 Results

3.1 Sample Characterization

These results are essential for understanding how students perceive and deal with issues related to water efficiency and water conservation, providing important insights for the development of educational strategies, environmental awareness, and the individual and collective responsibility of the student community.

The sample is constituted by 334 (50,4%) female, 324 (48.9%) male and 5 (0.8%) other genders. The majority of individuals, 66%, belonging to the 17–23 with 36% belonging to the 17–20 age category and 30% to the 21–23 age category, which was to be expected. However, 13.4% of respondents are over 33 years old, which is a notable deviation from the expected distribution.

Regarding their country of origin, 86.0% are Portuguese and 14% are foreigners. It is important to note that 54% are from urban areas and 46% from rural areas.

Of the students who responded to the survey, 69.4 per cent are studying for a graduate degree and 16.4 per cent are studying for a master's degree.

In terms of areas of study, Engineering and Technologies account for 50.8%, Medical and Health Sciences 11.8%, Agricultural Sciences 3.3%, Exact Sciences 0.8%, and Natural Sciences 3.2%.

3.2 The Significance of Water Resources

The importance of water resources was evaluated by means of a questionnaire comprising five statements on the subject:

- Water resources are essential for the livelihood and health of the environment;
- Water resources are essential for human activities;
- The availability of fresh water is low and limited globally;
- Today's society faces problems of water scarcity and pollution;
- Drinking water is an inexpensive resource.

In terms of the significance of water resources, the responses indicated that the HEI students are acutely aware of their importance.

According to the Cronbach's Alpha test, the answers had internal consistency (0.830), except for the water price, which depends on the region and the personal knowledge of the respondent.

In response to the question of whether "water resources are essential for the livelihood and health of the environment", 73.3% of respondents indicated a strong agreement, while 22.2% expressed an agreement. Similarly, regarding the importance of fresh water as a natural resource for the survival of all ecosystems, 86.3% and 10.3% of respondents, respectively, indicated a strong agreement and an agreement. Furthermore, it was noted that older students and women demonstrated greater levels of agreement, with stronger positive ratings being reported in higher percentages.

Respondents strongly agree (71.3%) or agree (23.5%) that "Water resources are essential for human activities", and women tend to strongly agree or agree more than men.

When asked if "The availability of fresh water is low and limited globally", 53.8% strongly agree and 32.3% agree. Older students, women and students of exact sciences or natural sciences are more likely to strongly agree.

A clear majority of respondents (64.9% and 28.1%, respectively) indicated that they strongly agree or agree with the statement that "Today's society faces problems of water scarcity and pollution." It can be observed that older students and women are more likely to express a strong level of agreement.

A different trend is observed when it is asked if "Drinking water is an inexpensive resource", 8.4% strongly agree, 22.6% agree, 23% have a neutral perception, 25.6% disagree and 11.3% strongly disagree. Women, social sciences and medical sciences students are more likely to disagree or strongly disagree.

3.3 Efficient Water Management

To understand the perception regarding the efficiency of different water management actions students were asked to rank 4 measures:

- Reducing leaks and water waste;
- Reducing consumption;
- Use alternative sources of water;
- Reuse and recycle water.

The measures identified as most relevant (ranked 1st) were "Reducing leaks and water waste" and "Reduce consumption" with 39% and 38% of answers, respectively. There are multiple studies that provide evidence of domestic water-saving due to the installation of flow reduction devices [14, 15] and the relevance of water leakage control [16, 17]. Students are therefore aware of the efficacy of these measures.

The measures "Reuse and recycle water" and "Use alternative sources of water" were ranked mostly in 3rd place (45% of students) and 4th place (70% of students), respectively. By ranking these two measures last could represent a reduced impact in water management but can also reveal increased perceived risks towards non-potable water sources. The acceptance of water reuse among high education students has been identified before but only for non-potable uses [18] or in applications that involve close personal contact [19]. In a study conducted in China, [20] concluded that increasing environmental education regarding reclaimed water reduced their perceived risk towards that alternative water source and increases their acceptability.

3.4 Sources of Information on Water Efficiency Measures

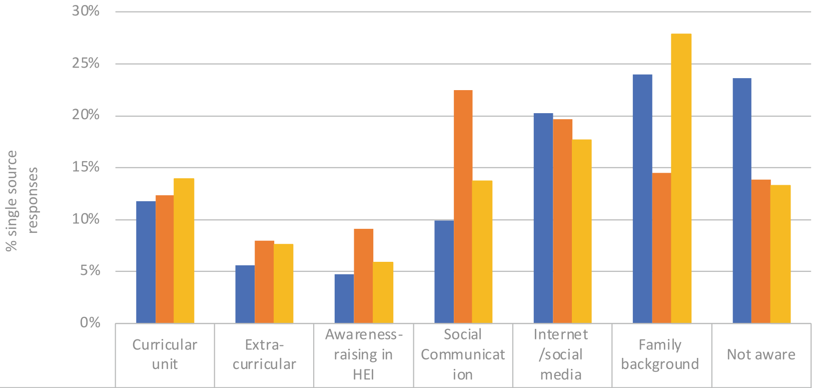
The sources of information regarding three water efficiency measures, namely "water saving equipment", "awareness-raising measures" and "water reuse", were identified through a questionnaire in which students were asked to select between seven options:

- Curricular unit,
- Extra-curricular workshop/training,
- Awareness-raising activities in HEI,
- Social Communication,
- Internet /social media,
- Family background,
- I am not aware of the topic.

Reponses that included the option "I am not aware of the topic" together with another option were considered invalid and were removed ($< 1\%$ of the total answers). Overall, more than 70% of the students selected only one information source regarding each measure. Two sources were reported by 16% of the students and 3% or less selected 4 different sources.

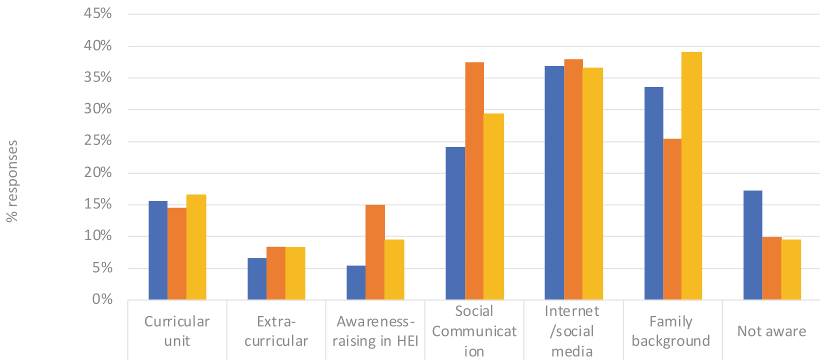
In single-source respondents, family background is the main information source regarding "Water saving equipment" and "Water reuse", with 24% and 28% respondents, respectively (Fig. 1). "Awareness-rasing" measures are mostly received through Social Communication (23% responses). "Curricular units" are reported by 12 to 14% respondents for the 3 water efficiency measures considered while "Extra-curricular" activities" and "Awareness-raising activities in HEI" are the information sources least reported with 5 to 9% of the answers.

Considering all of the information sources reported, it can be observed that "Social communication", "Internet and social media" and "Family background play the most relevant roles, accounting for between 24% and 39% of answers (Fig. 2).



	Curricular unit	Extra-curricular	Awareness-raising in HEI	Social Communication	Internet /social media	Family background	Not aware
Water saving equipments	11,8%	5,6%	4,8%	9,9%	20,3%	24,0%	23,6%
Awareness raising measures	12,3%	8,0%	9,1%	22,5%	19,7%	14,5%	13,9%
Water reuse	13,9%	7,6%	5,9%	13,7%	17,6%	27,9%	13,3%

Fig. 1. Sources of information regarding water saving measures for single-source respondents.



	Curricular unit	Extra-curricular	Awareness-raising in HEI	Social Communication	Internet /social media	Family background	Not aware
Water saving equipments	16%	7%	5%	24%	37%	34%	17%
Awareness raising measures	15%	8%	15%	38%	38%	25%	10%
Water reuse	17%	8%	9%	29%	37%	39%	9%

Fig. 2. Percentage of responses per water efficiency measure and per type of information source.

The highest level of information provided by these sources seems to be regarding "Awareness rasing measures" and "Water reuse". Only 10% of the students answered as "Not aware" of "Awareness raising measures" and "Water reuse", while 17% of the students reported not being aware of "Water saving equipment".

3.5 Connection Between Water Efficiency and SDG

In this study, the relationship between water efficiency and the Sustainable Development Goals (SDGs) was evaluated by inquiring about the extent to which each of the 17 SDG targets related to water efficiency. Students were permitted to select between three and ten options. Twenty-five percent of the respondents selected three options, 32 percent selected four to six options, 28 percent selected seven to nine options, and 15 percent of the students selected 10 options. Figure 3 illustrates the SDGs selected by respondents. It can be observed that SDG 6 – Clean water and sanitation was the most frequently selected option, with 70% of responses. SDG 2 – Zero Hunger, SDG13 – climate action, SDG15 – life on land and SDG 14 - Life below water were similarly selected at a rate of between 51% and 53%. This indicates that students perceive water efficiency in human activities to be directly associated with all SDGs that are directly related to water (SDGs 6, 14 and 15), as well as with human basic activities that can be affected by water (SDG 2) and climate change (SDG 13). In light of the assertion by UNWater that "climate change is primarily a water crisis" [21], it can be inferred that the majority of the surveyed students are aware of this connection.

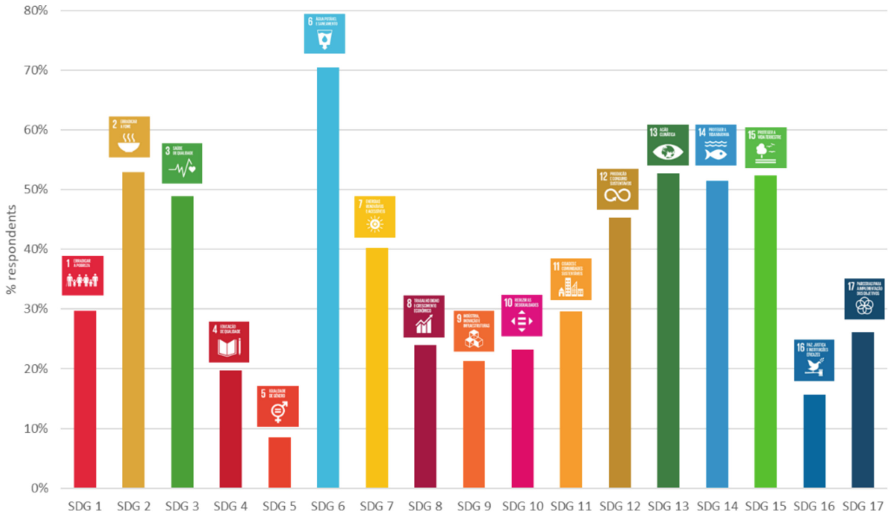


Fig. 3. Graphical representation of the paired responses between the options selected by each respondent.

The interconnectivity between SDG 6 and the remaining SDGs is also evident in Fig. 4, which illustrates the combinations (pairs) of answers provided by each respondent for the selected options. A solid line connecting both SDGs represents each combination of SDGs. The thickness and colour of the link indicate the frequency with which a specific conjunction was selected, thereby elucidating the interconnectivity between SDG 6 and SDG 2, 3, 12, 13, 14 and 15. It also shows that SDG 12, 13, 14 and 15 are often selected together, and also to SDG 2 and 3.

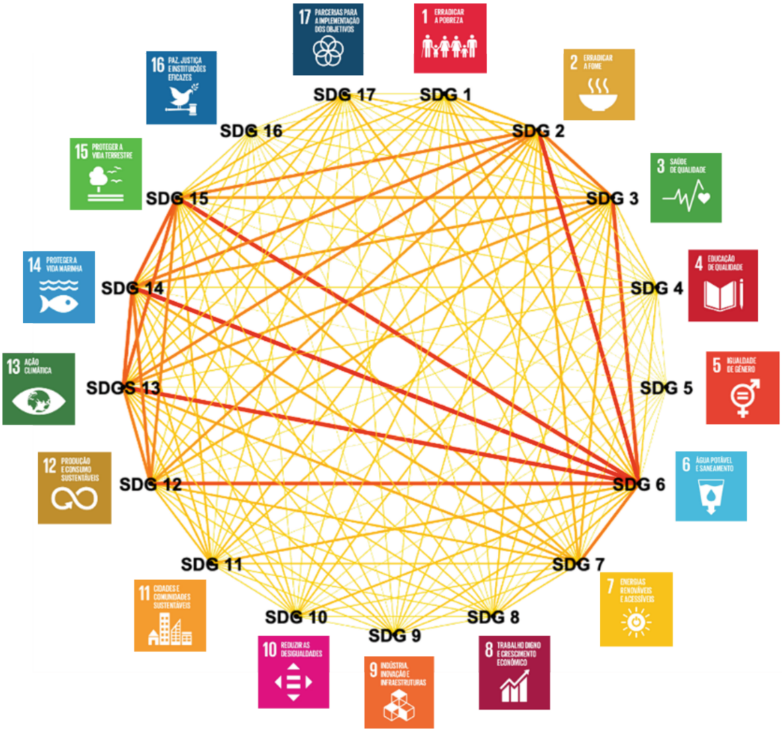


Fig. 4. Graphical representation of combinations (pairs) of answers between the SDG selected by each respondent.

4 Conclusions

A survey was conducted to 7 HEI in Portugal aimed at understanding student's perception regarding water efficiency measures and map the perceived link to SDG. The results showed that most students (>70%) strongly agree that the availability of water resources is essential for survival and for the protection of the environment, and that today's society faces problems of water depletion and contamination (65%). Students have identified the reduction of water consumption and water losses as the most relevant measures to improve an efficient water management, but the lower priority given to "Reuse and recycled water" and "use of alternative water sources" could result from a higher perceived risk associated to non-potable water sources.

The main sources of their knowledge about water efficiency identified by the students were 'social communication', 'internet and social media' and 'family background'. This demonstrates the importance of providing appropriate information through these sources, as well as the importance and relevance of intergenerational knowledge transfer. Future policies should include awareness raising campaigns in multiple information channels and include information regarding reclaimed water use to increase its acceptance.

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Cruise Ships Inspections, a Contribution to Sustainability

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Abstract. The United Nations' Sustainable Development Goals (SDGs) are aimed at securing the future for upcoming generations. This study sought to gather data relating to pollutant and greenhouse gas emissions, along with data from existing sensors within the vicinity of the Lisbon Cruise Port (TCL), to determine the impact of cruise activities on air quality. The research encompassed 47 distinct inspections. The analysis revealed that large cruise vessels predominantly use Heavy Fuel Oil (HFO) as their primary fuel source, while smaller to medium-sized vessels tend to favor Marine Gasoil (MGO). Despite MGO's higher calorific value compared to HFO, it was observed that MGO-powered vessels exhibit higher fuel consumption per ton in comparison to HFO-powered vessels. Regarding emissions, it was determined that the TCL terminal experiences a notable influence from ship emissions; however, these emissions do not significantly affect the city and do not substantially change air quality. Consequently, while the cruise industry remains imperfectly sustainable, the International Maritime Organization (IMO), the European Community, and the Port of Lisbon are implementing measures to ensure the achievement of sustainable development objectives.

Keywords: Cruisers · Sustainability · Emissions

1 Introduction

Cruise tourism is based on the transportation of passengers along a defined route and quickly becoming one of the most popular segments of this sector, especially by North American and European tourists [1, 2]. Due to its raising status, the industry has been forced to evolute, leading to luxurious and technologically advanced ships [3].

The cruises have a positive impact on the development of tourism and the economy worldwide[4]. However, it has a negative impact on environmental, as air quality, habitats, and climate [5]. Poor air quality, specifically particle emissions, is responsible for approximately 87 000 deaths from cardiopulmonary diseases worldwide annually, making it common to associate cruise ship pollution with mortality, morbidity, and respiratory infections [6].

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Maritime transportation increases the amount of atmospheric pollutants near metropolitan areas with ports, as carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), carbon dioxide (CO_2), and sulfur dioxide (SO_2) [7, 8]. Other pollutants are volatile organic compounds, heavy metals, and greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) [7]. Usually, cruises use fuels with a higher sulfur content, causing a large amount of SO_x emissions [9]. According to the distance to the next port of call, the ship can emit between 100 to 500 times more sulfur compounds than a normal car[9], and these emissions can reach up to 400 km away from the ship on land [6].

The International Maritime Organization (IMO) introduced regulations to minimize environmental impacts and contribute to achieving the Sustainable Development Goals outlined in the 2030 Agenda [10]. The IMO aims to reduce ship-related CO_2 emissions by up to 40% by 2030 [11], and implements measures to reduce pollutant emissions, especially SO_x emissions, mainly in more sensitive areas such as Emission Control Areas (ECAs) [10]. ECAs include the North Sea, the Baltic Sea, North American waters, and the Caribbean [12]. IMO 2020 establishes that ships use fuel with a maximum sulfur content of 0.5% by mass and within ECAs with a sulfur content of 0.1% by mass [12].

Applying the previous measures, IMO contributes to sustainability by improving air quality and public health, reaching SDG 3 (Good Health and Well Being), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) [10]. By reducing NO_x and SO_x emissions, it is also possible to minimize acidification of maritime waters, supporting with SDG 14 [13, 14].

To comply with the limitations introduced by IMO 2020, ships have the following options: 1. to use low-sulfur fuel; 2. Convert the entire propulsion system of the vessel to a cleaner and less polluting fuel, such as liquefied natural gas; 3. Install scrubbers onboard to reduce the emissions to a degree at least equivalent to what they could achieve using low-sulfur fuels [15].

Cruise ship fuels are divided into two categories: residual fuels, as Heavy Fuel Oil (HFO) and Light Fuel Oil (LFO), and distillate fuels, with Marine Gasoil (MGO) being the most used [11]. Residual fuels have sulfur contents of up to 3.5% by mass, while distillate fuels have a maximum of 0.5% [11, 16]. On the other hand, environmentally, public health, and resource exploitation levels, MGO, with low sulfur content, have results comparable to fuels considered more polluting. Environmentally and economically, it demonstrated worse results when compared to the use of HFO with scrubbers [17, 18]. As alternatives to MGO and HFO, more sustainable fuels emerge as alternatives for sector decarbonization. Some of these fuels include LNG, ethanol, biofuels, green hydrogen, ammonia, among others [11]. Another solution is the use of fuel-saving technologies such as Wind-Assisted Propulsion (WAPs) [19].

In 2022, the Port of Lisbon (PLx) was classified as the best cruise destination in Europe[20]. Consequently, maritime traffic has increased, as well as the concern to reduce the environmental impacts. As a measure to minimize emissions from cruises, despite not being in an ECA, PLx recommends that ships use fuel with 0.1% sulfur while in its area of influence [21]. Thus, this work aimed to collect data on pollutant and greenhouse gas emissions, as well as data from existing sensors in the Lisbon Cruise Terminal (TCL) influence area, and identify the impact that cruises have on air quality.

2 Methodology

The work developed at the TCL was based on collecting data from cruise ships through environmental inspections and from sensors existing in the influence area of the PLx in 2023, located as shown on Fig. 1. Also consulting information in the logistics platform of PLx (JUL) and the Vessel Traffic Services (VTS) and applying the Gaussian curve model to estimate the concentration of pollutants emitted by cruise ships in the measurements of the available sensors.

Station location:
- <u>Fixed Station</u> - 38º 42' 33,96" N 009º 7' 36,76"W
- <u>P2</u> - 38º 42' 44,88" N 009º 7' 30,65" W
- <u>Olivais</u>-38º 46' 11" N 009º 06' 26" W

Station sensors:
All the station has: CO, NO_x, SO_x, $PM_{2.5}$ and PM_{10} sensors.

Fig. 1. Map of Lisbon with location of the sensors and TCL.

Environmental ships inspections are part of the best practices carried out by the PLx and aims to collect, examine, and assess the environmental conditions of cruise ships, ensuring the compliance with national and international regulations in force. Inspections are carried out through a questionnaire that covers environmental issues reaching from waste management to ballast water management and fuel use. To carry out this work, the following points were added to the initial list: Ship consumption at entry/berth/departure in port, Engine model, Type of Scrubbers, Bunker delivery notes, NOx Reduction Methods, Loading Factor, Chimney height, Chimney diameter.

The data collected during the inspection was consolidated with JUL and VTS information, air quality monitoring reports, values measured by air quality and meteorological sensors located in the influence area of TCL.

The dispersion of pollutants was estimated using the Gaussian Curve model as a dispersion model [22]. This specific model was chosen because it considers the random distribution of pollutants in the plume, the relationship between pollution concentrations and emissions, and the empirical relationships between standard deviations and meteorological stability. Furthermore, this model ignores any possibility of long-term chemical reactions between the source and the receptor, as well as possible removal processes.

The following assumptions were made for this study:

- Ships with several calls at the Port of Lisbon always have the same behavior and fuel consumption recorded during the inspection.
- Ships considered "*sister ships*" have identical equipment installed and procedures, so they have identical fuel consumption and emissions.

- Obstacles were not considered in the calculation of pollutant dispersion using the Gaussian Curve model.
- The SO_x emissions from ships using HFO with scrubbers were estimated to have the same emission factor as MGO.

3 Discussion

3.1 Sample Characterization

A total of 47 inspections were conducted on different cruise ships that called PLx. Considering "*sister ships*" and the several date of calls of the same ship, the study covered a total of 145 calls.

Data collection allowed to identify which fuel type is most used according to the ship's Gross Tonnage (GT). Small to medium-sized ships (average GT of 73 555 tons) use MGO as their primary fuel, whereas larger ships (average GT of 103 297 tons) preferentially use HFO. As a result, larger ships are considered more polluting because they use fuel with a higher sulfur content and consume more fuel on average.

The ships' fuel consumption data was analyzed per GT during three distinct operational phases: entry maneuvering, hoteling, and departure maneuvering allowed to identify the fuel that the ships used per ton of ship and which fuel is more energy efficient (Fig. 2).

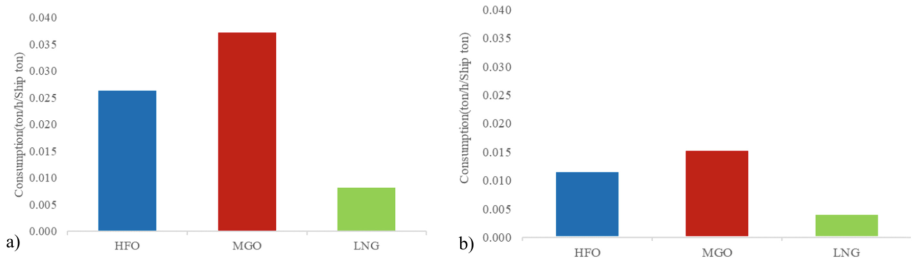

Fig. 2. Fuel consumption per ship tone during: a) the maneuvering; b) ship moored.

According to an analysis of the data shown in Fig. 2, ships using MGO consume the greatest amount of fuel per ton, followed by those using HFO, and then those using LNG. During maneuvers, ships using MGO burns approximately three times more fuel.

One of the most important properties of fuels is their calorific value, which is a physical property that indicates how much energy is released when the fuel is burned. The higher the calorific value of a fuel, the lower its consumption will be. LNG has the highest calorific value (48 MJ/kg), followed by MGO (42.7 MJ/kg), and finally HFO (40.2 MJ/kg) [23]. Therefore, it would be expected that HFO would be the fuel with the highest consumption per ton of ship. The ships operating with MGO have higher consumption per ton, so it leads to the conclusion that they have less energy-efficient equipment onboard.

3.2 Cruisers Ship Emissions Estimation

The amount of pollutants emitted per ton for the different fuel types used was calculated by simulating pollutant emissions applying emission factors (Table 1) and ship fuel consumption per ton (Fig. 3).

Table 1. Emission factors of pollutants dependent of the fuel used.

Pollutants	Emission factors (kg/ton Fuel)				
	MGO	HFO	LNG	HFO+Scrubbers	Ref[a]
CO	3.84	3.67	13.8	3.67	[8]
NO_x	72.2	69.1	4.92	69.1	[8]
SO_x	1.82	19.2	0	1.82	[8]
$PM_{2.5}$	1.4	5.6	0.00106	5.6	[8, 24]
PM_{10}	1.07	5.2	0.00124	5.2	[8]

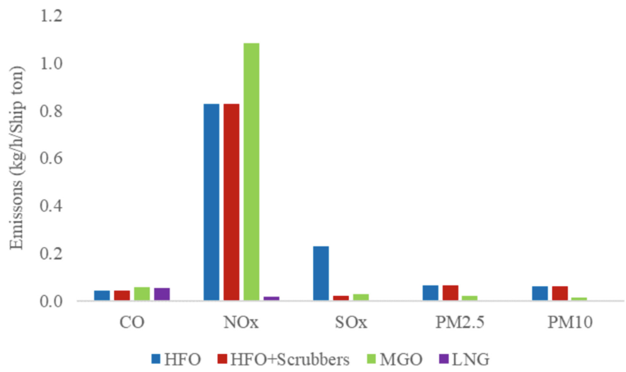

Fig. 3. Comparsion between polluants emissons for MGO, HFO and LNG.

The comparison of pollutant emissions in Fig. 3 shows that when ships use HFO, SO_x and particle emissions are significantly higher. However, when MGO is used, a significantly greater amount of NO_x is released than other pollutants. It is also evident that utilizing scrubbers in conjunction with HFO can significantly lower SOx emissions. LNG has been demonstrated to have the lowest emissions, despite having a value that is comparable to other fuels when measured in terms of CO.

Additionally, estimates of CO_2 emissions for MGO and HFO were provided. An emission factor of 3 179 kg/ton fuel has been used for this [25]. Using MGO ships emit approximately 47.69 kg/h/ton of CO_2 per ship ton, whereas ships using HFO emit 38.15 kg/h/ton, 25% less.

Therefore, compared to NO_x, SO_x, and particle emissions, LNG exhibits negligible emissions, confirming its status as “the cleanest fuel”. Nevertheless, the primary gas that makes up LNG is methane, and using it increases emissions of this gas, which has an 82.5-fold greater potential for greenhouse effect than CO_2 [9].

The Gaussian Curve model was used to estimate emissions. It calculated the contribution of two ships with similar dimensions and different fuel types that were at PLx on the same day and at the same hours. Ship A uses MGO as fuel and ship B use HFO. Real data from the two ships was used to make the estimate. Ship A has a size of 71 304 tons and ship B has a size of 58 119 tons, making ship A 22.67% larger than ship B.

Ship B had closed-loop scrubbers and a Selective Catalytic Reduction (SCR) system for NO_x reduction. The scrubbers will reduce SO_x emissions to values equal to those of ship A. On the other hand, NO_x emissions for ships with SCR are determined by revolutions per minute (RPM) and engine power, according to IMO [26]. According to the collected data, the engine has 5 400 kW of power, was operating at 70% of its total power, and has a maximum of 720 RPM. Thus, NO_x emissions are equal to 9.7 g/kWh.

Table 2 shows the average concentration value measured in the different air quality stations considered for the study ("Real"), the results after applying the Gaussian Curve model and accounting for an 8-h stay in port for each ship and air quality stations, and the overall pollution estimated (A + B). For every ship, the estimated concentration was added (A + B). The sum was made because the surrounding conditions were identical while the ships were moored at the same day.

Table 2. Pollutants dispersion results and real values measured by sensors.

Sensor	Ship	CO (mg/m^3)	NO_x (mg/m^3)	SO_x (mg/m^3)	$PM_{2,5}$ (mg/m^3)	PM_{10}(mg/m^3)
Fixed Station	A	13.48	253.3*	6.4	4.92	3.74
	B	8.4	120.29*	5.97	12.83	11.91
	A + B	**21.88**	**379.59***	**12.37**	**17.75**	**15.65**
	Real	**0.2**	**68.9***	**1.9**	**11.2**	**19.4**
P2	A	2.02	37.9	0.96	0.74	0.56
	B	1.26	17.99	0.89	1.92	1.78
	A + B	**3.28**	**55.89***	**1.85**	**2.66**	**2.34**
	Real	**0.2**	**61.2***	**1.2**	**14.6**	**11.9**
Olivais	**A**	0.14	2.62	0.07	0.05	0.04
	B	0.09	0.89	0.06	0.13	0.12
	A + B	**0.23**	**3.51**	**0.13**	**0.18**	**0.16**
	Real	**0.3**	**22.1**	**4.3**	**8.6**	**20.5**

* Value exceeds the WHO Guidelines[27]

The different pollutants concentration in Table 2 revealed that:

- The estimated concentration of CO, NO_x, and SO_x consequence to the ship A´s emission is always higher than from the ship B. The opposite occurs for particle concentrations (PM_{10} and $PM_{2.5}$).

- All the simulation value and "real" concentration of NO_x at "Fixed Station" are higher than 25 mg/m^3, the WHO guidelines [27]. The same happens at station "P2" for the real measured values and for the contribution of the two ships (A + B).
- The simulation value for all concentration in "Fixed station" is higher than "real" with exception of PM_{10} concentration. This may be due to the assumption that the Gaussian curve would not consider obstacles in the path of pollutants. Since the fixed station is close to the cruise terminal building, it may have acted as a barrier, explaining why the measured emissions are substantially lower than expected.
- Analyzing sensor P2, it was found that only the concentrations of pollutants CO and SO_x are above the measured values, while the other pollutants represent a significant portion of the values measured by this sensor. Specifically, 91.3% of NOx, 18.2% of $PM_{2.5}$, and 19.7% of PM_{10} are predicted to be derived from ship emissions. Comparing with the WHO limits NO_x continues to be the one that exceeds the limit.
- On the other hand, at the Olivais station, the values estimated by the model are lower than the real. Considering the large distance between Olivais air quality station, and TCL, it is expected that the influence of traffic and other sources of pollution grows.

4 Conclusion

The use of HFO with scrubbers offers advantages over MGO due to reduced SOx emissions. However, LNG emerges as the most beneficial fuel overall, despite relatively high CO emissions. LNG aligns best with Agenda 2030 SDGs, particularly promoting energy efficiency (SDG 7) and lower emissions (SDG 11 and SDG 13), contributing to SDG 3 and SDG 14.

Ports can play a role in emission reduction by providing power supply centers for ships, like the Port of Lisbon's project, offering renewable electricity to docked ships to achieve zero emissions. This aligns with SDG 11, benefiting both population health and logistics.

Ports can also promote cleaner fuels by reducing port fees based on emissions reports, encouraging sustainability and competitiveness among companies.

Continued assessment and monitoring of air quality around ports, like the Lisbon Cruise Terminal, are essential to develop and implement further sustainability measures.

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Use GIS Tool for Biomass Management: A Case Study for Portugal Within the TANGO-Circular Project

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Abstract. This study, part of the TANGO-Circular Project, employs Geographic Information System (GIS) tools for biomass management in Portugal. The project, spanning five European countries (France, Greece, Italy, Portugal and Spain), aims to advance agricultural waste utilization through innovative technologies. This study, albeit preliminary, focuses on the implementation of GIS to plan and map the valorization of agricultural residues. Thematic maps, generated through open-access software (Q-GIS), illustrate the spatial distribution of biomass types such as forest residues, cereal straw, pruning residues, livestock manure, agro-food industries by-products, organic urban waste, and agricultural plastic waste. These maps, presented at Nuts 3 levels, provide valuable insights, supporting the project's goal of fostering sustainable biomass management within a Circular Economy framework.

Keywords: Sustainability · circular economy · biomass · GIS

1 Introduction

The TANGO-Circular Project, funded by Erasmus+, involves the participation of five European countries in the Mediterranean region (France, Greece, Italy, Portugal and Spain). The main objective is to develop an educational program incorporating cutting-edge technologies related to the collection, transport and valorization of agricultural wastes. The program also covers essential information on legislative, economic, social and technical aspects, providing EU producers with comprehensive knowledge, from basic to in-depth understanding [1].

The project's objectives are realized through a Quadruple-Helix approach, engaging Public Authorities, VET providers, Private stakeholders, and the Civil Society. A central initiative of the project involves establishing "Rural Labs" coordinated by Universities

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with expertise in agricultural waste management. These labs serve as platforms for training farmers and other agricultural stakeholders. The primary focus of these Rural Labs is to implement innovative, interactive training models that combine on-site training with the integration of new information and communication technology tools. These tools are developed to benefit a broader audience of trained individuals, both within the Project Countries and throughout the rest of Europe.

Within the scope of the project, a task was carried out with the purpose of implementing Geographical Information System (GIS) technologies to enhance the planning of agricultural waste valorization, and this article was developed within the context of that task. The integration of GIS technologies in waste valorization planning aligns with the broader initiative addressing waste biomasses, which act as dispersed energy sources across vast geographic areas. The need for collection and transport to nearby conversion plants is highlighted in the context of a comprehensive energy spatial planning process. This process considers different factors, including temporal and spatial aspects connecting biomass resources, waste biomass, conversion plant size, transportation systems, and environmental impacts. While assessing relevant quantities of biomass, geographic distribution is emphasized as a critical aspect.

Initiatives to integrate energy production models with spatial infrastructure are in line with the overarching objective of establishing a versatile spatio-temporal analysis framework for long-range planning, considering potential system configuration adjustments in targeted regions. The emphasis on biomass mapping, measuring waste and by-products, directly contributes to the development of an sustainable reuse and recycling supply chain, furthering the project's objectives and providing valuable insights for policymakers and investors evaluating local biomass utilization for bioenergy or biorefinery processing. The geographic nature of biomass mapping also plays a crucial role in interfacing with bioenergy traceability systems, ultimately guiding the modelling of the most suitable bioenergy-biomaterial mix in adherence to sustainability criteria.

The present study was conducted within the framework of the TANGO-Circular Project, aiming to effectively plan the utilization of agricultural waste and facilitate data sharing within the context of Portugal.

2 Materials and Methods

The methodology employed in this study follows the approach outlined in Deliverable D.3.2. of the TANGO-Circular Project, titled "GIS for planning the valorization of agricultural wastes and sharing data among partners."

This methodology is based in quantifying agricultural waste flows, including both organic and non-organic waste from agro-industrial activities; and mapping the spatial distribution of these waste flows.

The estimation process involved analyzing the annual local availability of residual biomass from various agro-industrial sources, including agricultural and agro-food co-products, by-products and wastes. Estimating annual quantities is complex and depends on factors such as climate, crop productivity, waste production and utilization rates. The methodology encompasses different types of biomass derived from agricultural and agro-food products, as well as non-organic materials like agricultural plastic waste.

Operationally, the process included the following steps:

1. Selecting crops with by-products suitable for reuse.
2. Determining the areas and related productions concerning the main product at harvest.
3. Calculating the quantity of by-product in relation to the mass unit of the main product.

The collected data were organized into a geo-database and processed using open-access software (Q-GIS). GIS enables graphical assessment of biomass distribution and creation of thematic maps. Through these analyses, the potential availability of different types of biomass can be determined.

2.1 Analysis and Calculation

The data concerning land use and cultivation was analyzed and computed within GIS software (Q-GIS). This analysis includes the potential of agricultural, animal, forestry and municipal wastes. The analysis was conducted primarily at the NUTS 3 level (delineates smaller regions for specific diagnoses), which served as a reference unit. However, in instances where this level of spatial analysis couldn't be achieved, the regional level NUTS 2 was considered.

The results are illustrated through maps, with the objective of delineating resource distribution, projecting potential scenarios for global environmental protection and providing essential guidance tools for policymakers and landscape managers involved in land use planning.

Theoretical availability calculations, contingent upon factors like climate, land use, topography, etc., have been refined through appropriate constraints, considering current technological limitations.

All spatial tasks were executed using Q-GIS version 3.10, an open-source software capable of determining the spatial distribution of the agricultural by-products under consideration. Using GIS data in vector format, information has been integrated to calculate values across the entire spatial area with geographic reference [8].

2.2 Forest Residuals

The estimation of biomass generated from forest management operations was conducted using the areas of forest (expressed in hectares) obtained from National Statistical Institute. Subsequently, the land areas were multiplied by the average annual biomass increment [2]. The total forest residues are expressed in tons.

2.3 Cereal Straw

To understand the spatial diversity among different crops, data acquired from agricultural censuses or sourced from CORINE LAND COVER was analyzed.

Utilizing this information, the quantities of straw for each crop were calculated based on average residue yield values as outlined in Table 1 [8].

Table 1 Residue yield (Source: Picuno et al., 2023)

Crop	Residue yield (t/ha)
Wheat	3.627
Barley	4.216
Rye	5.625
Oats	3.76
Maize	7.84
Other cereals	3.6

2.4 Pruning of Trees

Mediterranean fruit plantations yield substantial quantities of ligneous biomass through pruning operations, which can be repurposed for different applications. By utilizing agricultural surface data and an average estimate of pruned biomass (Table 2), the total amount of pruning residues at a spatial level was calculated [3, 4, 8].

Table 2 Pruning residues (Source: TANGO-Circular, 2023)

Trees Crop	Pruning residues (t/ha)
Olive grove	2.16
Vineyards	2.15
Fruit trees	2.20

2.5 Livestock Manure

Considering the current livestock units and the overall quantity of livestock manure in Portugal and based on the standard manure production rate per animal per year as outlined in [5] (Table 3), the total manure production was estimated in tons of dry matter per head and year [8].

2.6 Agro-Food Industries By-Products

The most prevalent agro-food residues in Mediterranean Europe result from traditional crops such as olive trees and vineyards. These include vine shoots, fresh and senescent leaves, lees, grape skins, seeds, vineyard stalks, as well as olive tree leaves and olive pomace from olive groves. However, certain by-products like whey and shells couldn't be estimated due to insufficient data availability.

When possible, the annual quantity of pomace was calculated by considering olive production data (in tons) and assuming an average by-product yield of 40%. Additionally, approximately half this amount was identified as exhausted pomace.

Table 3 Manure production rate per animal per year (Source: Picuno et al., 2023)

Livestock (units)	Manure production rate (t.d.m./head)	Recoverable (%)
Cattle	1.69	25
Pigs	0.21	85
Sheep & goats	0.28	10
Poultry	0.01	85

Regarding wine grapes, 4.6% of the total amount of exhausted grape marc was considered.

2.7 Organic Fraction of Urban Waste

Considering the population in Portugal and the average amount of organic waste generated per inhabitant (121 kg/year according to [6]), the total amount of urban organic waste was calculated at the spatial level.

2.8 Agricultura Plastic Waste

For Portugal, the data on plastic usage in agriculture were extrapolated (Table 4), assuming similar growing conditions across the Mediterranean basin. When available, specific data about greenhouse cultivation or intensive crop practices were utilized to estimate the amounts of plastic waste.

Table 4 Use of plastic material in crop production (Source: Picuno et al., 2023)

	Use of plastic (kg/ha)
Horticulture industry	14.86
Horticulture crop	20.04
Tomato	7.67
Forage	111.16
Pomegranate	0.91
Blueberries	0.02
Citrus fruit	3.59
Almond	297.12
Nut	7.07
Vineyard	18.30
Grape	773.58
Olive grove	1272.36

3 Results and Discussion

Figures 1, 2, 3, 4, 5, 6, 7, and 8 present the results in the form of thematic maps. The utilization of GIS for data analysis and processing offers a significant advantage in promptly visualizing results, given the inherent capability of GIS systems for geo-referencing data. Therefore, through the visualization of the generated maps depicting different types of by-products at the national level, a comprehensive understanding of their availability in Portugal.

As previously mentioned, the data are presented at the provincial level (NUTS 3). In cases where this level of detail was unavailable, they were provided at the regional level (NUTS 2).

Through mapping, it is possible to identify the areas within the national territory where the highest/lowest total biomass production is concentrated. This dispersion is primarily related to the available/used agricultural land area and the agricultural activities carried out there [7].

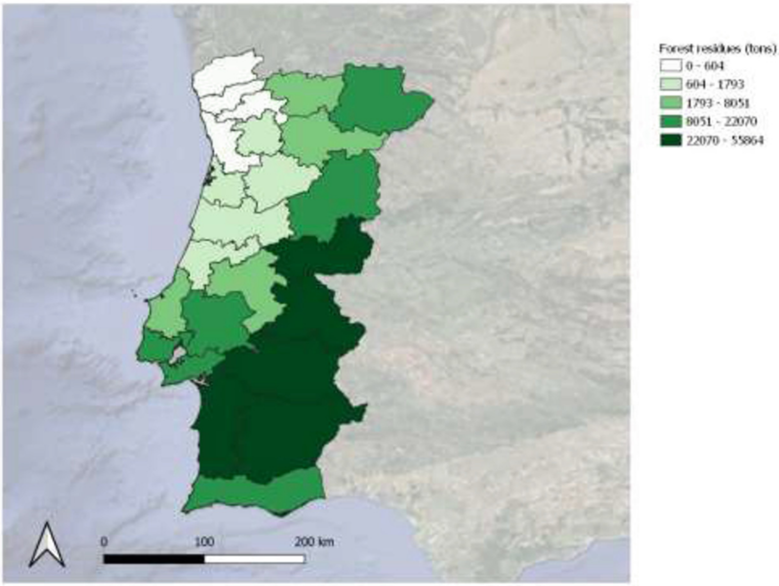

Fig. 1 Estimation of forest residues

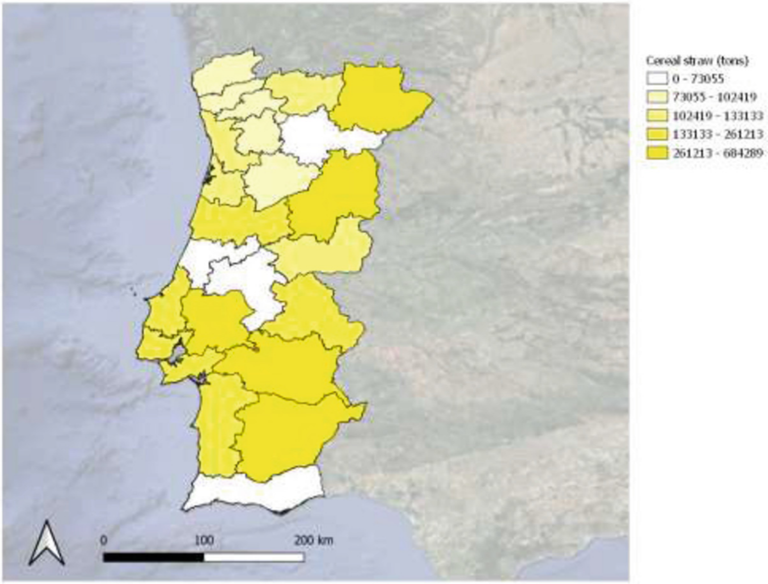

Fig. 2 Estimation of cereal straw

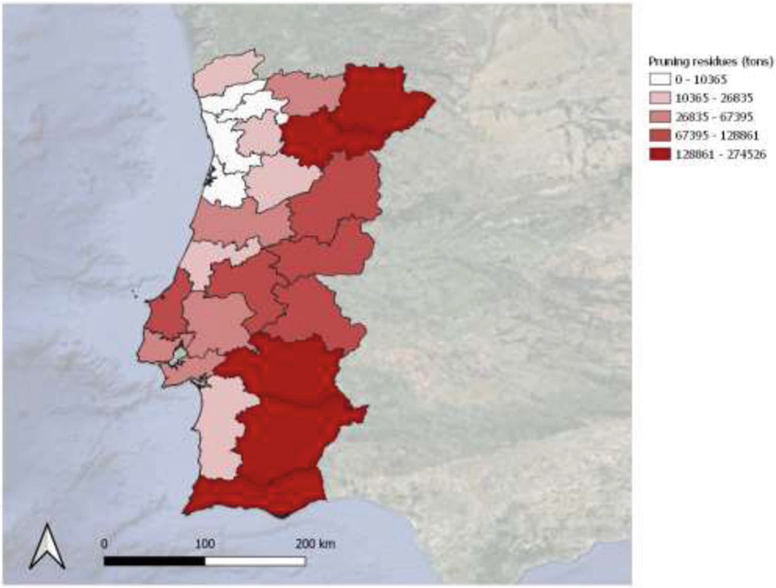

Fig. 3 Estimation of pruning residues

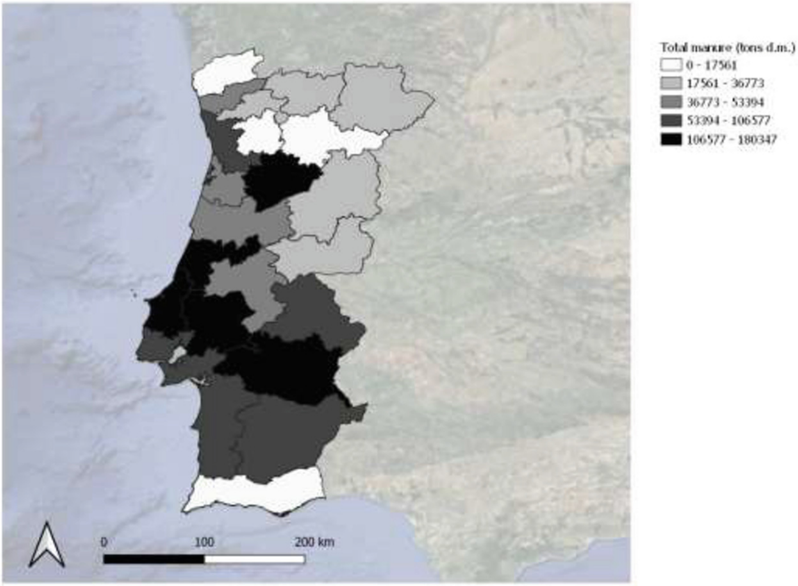

Fig. 4 Estimation of animal manure

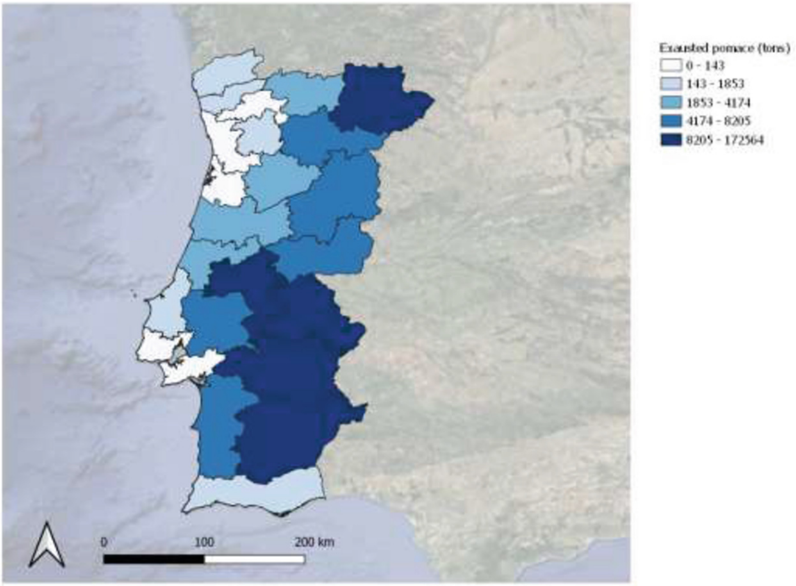

Fig. 5 Estimation of exhausted pomace

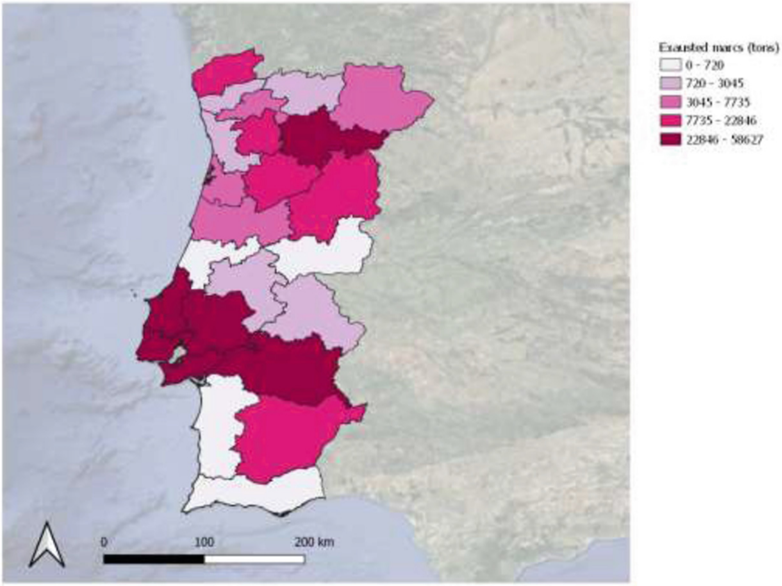

Fig. 6 Estimation of exhausted marcs

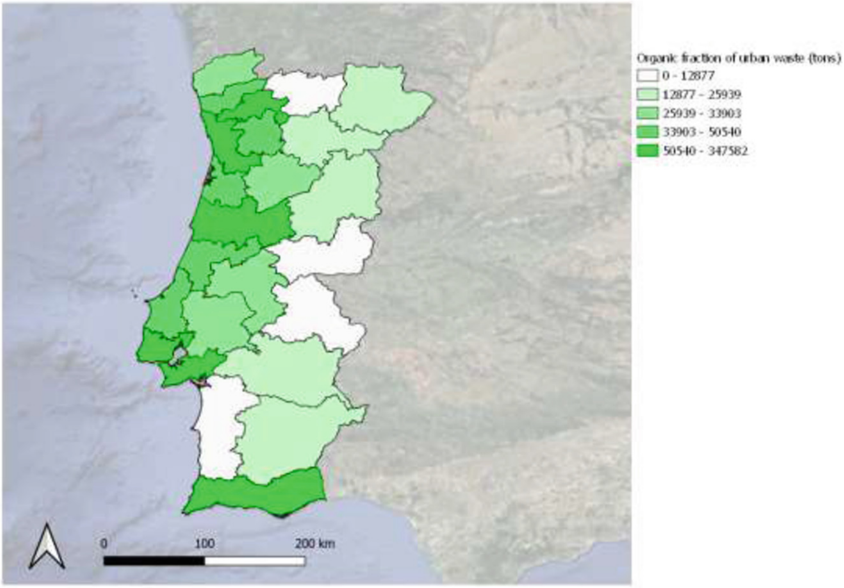

Fig. 7 Estimation of organic fraction of urban waste

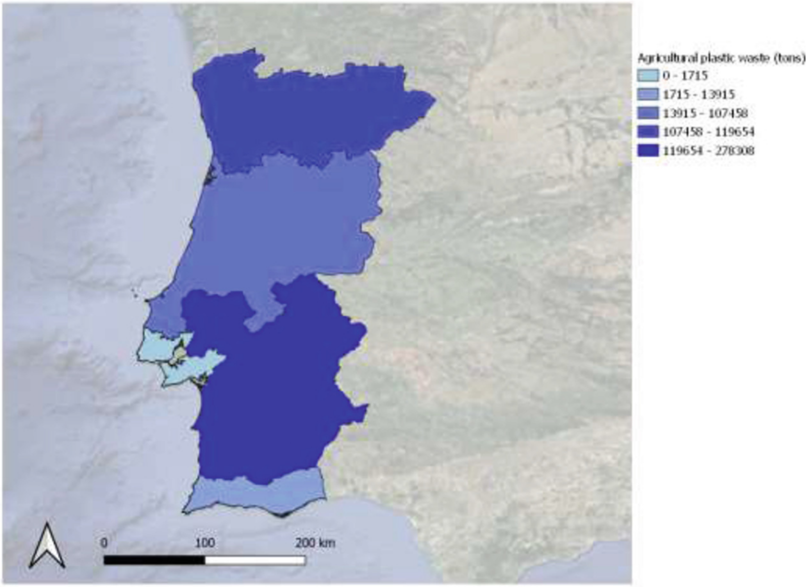

Fig. 8 Estimation of agricultural plastic waste

4 Conclusions

The Geographic Information System (GIS), implemented within the scope of the Project, provides a comprehensive approach for the analysis and management of agricultural waste. GIS mapping allowed for the identification of key biomass/plastic production regions. Additionally, the system facilitated specific analysis of the type of biomass/plastic and the quantities of waste generated in each area.

The proposal for expanding waste collection areas in strategic zones, based on prior economic analyses, and the efficient direction of waste flow to predefined recycling companies aim to optimize the materials cycle within a Circular Economy perspective. This approach helps to avoid hindrances for small recyclers and disruptions in large companies due to agricultural waste shortages.

Acknowledgements. The TANGO-Circular Project is Co-funded by the Erasmus+ Program of the European Union (Project: 101055970 — TANGO-Circular — ERASMUS-EDU-2021-PI-ALLINNO).

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Barriers, Drivers and Opportunities for Valorization of Agricultural Plastic Waste

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Abstract. The rise in world population and its corresponding demand for increased food production has led to the widespread adoption of plastics in modern farming techniques. Non-existent or inadequate approaches to recovery, recycling and reclamation of agricultural plastic waste has led to the accumulation of these residues in landfills and/or their improper disposal, exacerbating environmental problems, particularly soil and water pollution, and threatening ecosystems and their services. Such inappropriate waste management approaches and their impact on soil and water health will ultimately pose a threat to food security. This work aims providing an overview on current Nacional/European/International methodologies, policy instruments and management tools applied to collection, recycling and valorization of agricultural plastics. The work will in addition identify current Portuguese Legislation gaps in this area and provide guidance on possible solutions specifically, policy instruments and regulatory frameworks, collection schemes and technical approaches for valorization of agricultural plastic waste and soil remediation approaches.

Keywords: Agricultural Plastic Waste · Valorization · Recycling · Public Policies Sustainability

1 Introduction

Legislation associated with the selective collection and recovery of plastic waste has been focused mainly on packaging, a sector which made up to around 60% of the total 29.5 million tons of plastic waste collected in 2020 in the EU [1]. The recovery of

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this and other plastic waste has increased recycling and energy recovery, encouraged separate collection and minimized landfill. Plastic waste from agriculture is a particular case, accounting for around 1.5 million tons and 5.1% of the total plastic waste collected in the EU. The lack of specific legislation and management models for plastics used in agriculture in most European countries (only 6 European Countries have specific legislation for this waste) has led to their accumulation in soil and water, with negative impacts on food safety, ecosystems and associated services. The increase in the world's population, estimated at 11.2 billion, and the need to increase food production by around 60 per cent by 2100, presume a significant increase in the use of plastics in agriculture [2]. In the absence of appropriate collection and management systems, they end up being abandoned, burnt, or buried near farms. The subsequent degradation of plastics due to exposure to environmental and physical factors leads to the formation of microplastics, which accumulate in the soil, negatively affecting essential functions such as the microbiome, compaction, porosity, etc. The possible migration of microplastics to fauna and flora can jeopardize food safety [3–6]. In addition to these environmental challenges, there are also other associated social and economic problems, which mainly affect farmers and waste collection companies: i) lack of infrastructure and systems for collecting, storing and managing waste; ii) lack of knowledge of good collection, sorting, separation and recovery practices; iii) lack of legislation governing management and recovery; iv) lack of incentives for collection and recovery; v) lack of knowledge of the value associated with waste recovery.

The volumes of plastic used in Portugal in agriculture are considerable: in the Alqueva irrigation zone only, around 1,880 tons of plastic were used in 2018, with an expected annual increase of around 3,500 tons [7]. Specifically, in Odemira, an important agricultural area in Portugal, an increase of up to 4800 hectares of greenhouses, corresponding to the use of around 16,800 tons of plastic, is expected [8].

Many of the existent technologies adequate for recycling and valorization of agricultural plastic are not always easily applicable in Portugal, mostly due to the absence of appropriate political instruments and governance models, promoting and/or mandating the recovery of agricultural plastic waste, which make the access to this type of waste rather difficult. European directives and Portuguese legislation relating to plastics are essentially focused on implementing mechanisms to reduce the environmental impacts of their misuse and are extremely focused on single-use plastics and packaging. A revision of these directives, adjusted to the needs of this specific class of waste, with a view to its recovery, is therefore necessary. In addition, it is essential to develop awareness-raising and dissemination actions among farmers, associations and other relevant actors, in order to improve literacy in relation to this waste, raise awareness of the development of behaviors that promote the circular economy, value this agricultural waste and guarantee the conservation of natural resources.

Within this work we will attempt to clarify the importance of the use of a transdisciplinary, multi-actor approach that integrates and proposes solutions for the collection, recycling and recovery, taking into account political, social, economic and environmental aspects, in order to maximize the recyclability potential of plastic waste from agriculture. Main barriers, essential drivers for an integrated recycling and valorization process and main opportunities associated with recycling and valorization of agricultural plastic waste are depicted on Fig. 1. Aiming at the development of an integrated approach for agricultural plastic waste recycling and valorization, we will be covering and discussing different relevant aspects such as: i) identification of approaches promoting knowledge among the different stakeholders about good international practices in the collection and recovery of plastic waste from agriculture; ii) identification of gaps and necessary changes to current Portuguese policy instruments, e.g., the strategic plan for non-urban waste (PERNU), APA's National Waste Management Plan 2030 (PNGR 2030) and other relevant national strategies and plans (Bioeconomy Strategy, Carbon Neutrality, etc.); iii) proposals for economic instruments, standards and incentives to promote the recycling of this waste and its use and incorporation in the development of new products and iv) proposals for integrated models for collecting and recovering this waste that enable the development of technically and economically viable, competitive and sustainable solutions and business models that guarantee environmental protection.

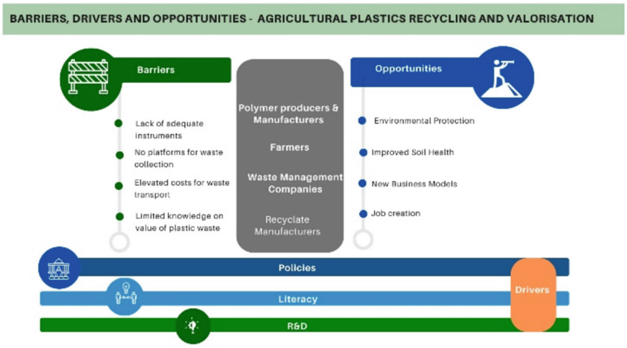

Fig. 1. Barriers, drivers and opportunities: agricultural plastics recycling and valorization

2 European and Portuguese Legislative and Governance Frameworks

The lack of specific legislation and governance models in Portugal for the management of plastic waste from agriculture has led to inadequate management, high landfill rates and the accumulation of this waste in soils and watercourses adjacent to the farms where it is used, with significant environmental impacts. Given the growth in the world's population, current projections indicate a significant increase in agricultural production (around 60 per cent), and consequent increase in plastics used in agriculture. The main applications of plastics in agriculture are, in descending order: silage films, greenhouses and tunnels, roofing films, irrigation pipes, netting and twine. In 2014, the plastics industry estimated that 28% of the agricultural plastic waste collected was recycled, 30% was sent for energy recovery and 42% was landfilled. Data from Plastics Europe from 2020 indicates that there has been no improvement in terms of recycling and valorization of plastics from agriculture, with the percentage of plastics sent to landfill remaining the same as in 2014 [9]. In addition to the high numbers of plastics deposited in landfill sites, there are also plastics that are illegally burnt and abandoned near farms. European directives and Portuguese legislation related to plastics have essentially focused on implementing mechanisms to reduce the environmental impacts of their misuse, focusing on single-use plastics and packaging plastics. Specific reference to other types of plastics, particularly plastics used in agriculture, is non-existent or very limited – of the 27 EU countries, only 6 have specific legislation linked with agricultural plastics. Exceptions are: i) the specific legislation for plastics from agriculture which will ban the use of fertilizers with a non-biodegradable polymer coating by 2026, and the Decree-Law 187/2006 of 19 September, which regulates plastic waste used for storing plant protection products. In addition there is also the Portuguese Decree-Law no. 102-D/2020 of 10th of December, which establishes the general waste management regime, and Decree-Law no. 178/2006 of 5th of September, which aims to make waste producers responsible for the final destination, management and transport costs, and which prohibits open burning, burial and abandonment. APA's National Waste Management Plan 2030 (PNGR 2030) provides for the implementation of the Strategic Plan for Urban Waste (PERSU) and for Non-Urban Waste (PERNU). These plans make no specific reference to plastic waste from agriculture. Another important aspect and issue is the fact that agriculture plastics are not considered municipal waste, which practically means that they can only be managed at commercial level through municipal waste management systems (SGRUs). Lack of adequate policies, and inexistence of appropriate dismantling, collection and storage systems, maximizes the risk of abandonment and exposure of waste to contamination and degradation, making its reuse, recycling and recovery technically and economically unviable. The channeling and landfilling of this waste is than left as the main solution. In the Alentejo region, for example, plastics from agriculture are landfilled at the industrial landfill site in Beja. Forwarding this waste is *per se* associated with a high carbon footprint and considerable costs for farmers. The small number of private operators who can manage this waste and direct it to companies that can recover it, the high collection costs, the lack of tax incentives and other political instruments that can motivate the collection and forwarding of this waste for recovery, lead farmers to opt for burning and abandonment, both illegal practices with high environmental costs.

In short, of the various EU and national directives created under the EU's strategic waste framework, there is no legal framework specifically focused on plastic waste from agriculture, which could serve as a basis for developing legally binding rules, procedures and objectives to promote the management and recovery of this waste.

3 Possible Routes for Sustainability: Polymer Design, Plastic Waste Valorization and Soil Decontamination

3.1 Polymer Design

Over the years polymer design targeting agricultural films has focused on the development of materials improved lifespan and processability. This has been achieved through the introduction of specific additives (e.g. anti-UV additives) and improved rheological properties, targeting and optimization of film thickness, during processing of agricultural films. Another approach to improve lifespan has been through the use of mulch films with higher thicknesses. Besides the increase of lifespan, research has shown that the removal process of end-of-life of thicker films is more effective, significantly increasing the retrieval rate and thus increasing the recycling and valorization potential. According with previous research [10, 11] thicker films perform better in terms of their benefit to the crops; fields where thicker PE mulching films were applied had the highest grain yield, as well as a lower release of phthalic acid esters (PAEs) into soil compared to biodegradable films. Unfortunately, in the absence of regulations defining minimum thickness for mulch films, the choice of the mulching film thickness is left to farmers, which are driven by costs rather than by efficiency, performance and lifespan. Recently agricultural films have been made from recycled polymers originating from agriculture. End-of-life films from greenhouses are particularly interesting for recycling, due to their limited degradation over the time, associated with the heavy stabilization packages used in the virgin materials. Development and application of adequate dismantling and collection schemes could enable a closed-loop recycling of these films, and reuse in similar end applications. Good-quality recycled materials from greenhouse and low tunnel films were obtained by blending of these with their HDPE film coverings, noticeably without additional additivation [12]. For materials characterized by a high level of contamination, improvements in material homogeneity and ductility might be achieved through additivation, e.g., maleic anhydride-grafted polyolefins, SEBS block copolymers, EVA copolymers, or paraffin wax [13]. The addition of agricultural scraps to biopolymeric plastic matrices has been presented as an alternative to reduce plastic usage, thus decreasing costs, promoting an eco-friendlier process, and targeting a more circular economy approach. In addition to the advantage in terms of lower usage of plastic, this approach has shown to accelerate matrix biodegradability while enhancing mechanical performance [14]. This is another very promising approach to consider for the production of more sustainable plastic for agricultural applications.

3.2 Polymer Waste Recycling and Valorization

Mechanical recycling, chemical recycling and solvent based recycling appear as prominent approaches for valorization of plastic waste. Due to the composition, water content, contamination type and contamination levels, mechanical recycling has been sofar the preferred valorization method for agricultural plastic waste. Agricultural mulch films are by far the ones more difficult to valorize, due to their contamination, with soil, degraded additives, metals, stones and other chemical contaminants (such as residues from phytopharmaceutical products). Prior to shredding and application of a given recycling process, these materials need to be subject to appropriate cleaning and decontamination. Although technically feasible this process can be cumbersome and expensive, considering that, in some cases, the residue percentage can be within the range of 40 to 50%. Recent advances in mechanical recycling, which included development in terms of advanced cleaning, pre-treatment and separation technologies through NIR, hyperspectral analysis, applied for the segregation of materials upstream the mechanical recycling process, combined with advanced filtering units, degassing, and extruder profile combinations adequate for improved mixing, have led to an improvement of the overall properties of recyclates [15–18]. Specific technological developments enabling improved separation, segregation, decontamination, washing, and shredding, specifically adjusted to the special requirements of agricultural film recycling (high contamination, high moisture, high degradation) have occurred in recent years, enabling their use into new applications such as new agriculture film, bags for storage, garbage bags, furniture, fences, damp-proof membranes, etc. [15–18].

Alternative options for the valorization of plastic waste include, use of the waste materials within the production of building materials, road pavements, green roofs, bricks, garden furniture, stakes for various crops (e.g., vineyards, fruit orchards), footpaths (plastic decking and lumber), asphalt mixes, railway sleepers, and many others, like sneakers and other fashion items, etc. [19–22]. Other thermal and thermo-chemical driven processes were used to produce alternative from agricultural plastic waste, namely adsorbents, gases with energy value, and biofuels [23–25]. The adsorbents in particularly interesting, has they can be used on applications aiming the removal of hazardous molecules and pesticides present in the aqueous phase [25, 26]. The production of hydrogen for energy purposes, the use of thermochemical gasification for the production of energy and syngas have been alternatively use for plastic waste valorization and HTC (hydrothermal carbonization) have also been used for the valorization of polymers and biomass waste [26–28]. With the persistent rise in the cost of traditional fossil fuels sparked as a result from conflicts, have led to a growing demand for alternative liquid fuels [29, 30], prompting the development of alternative technological processes using biowaste and agricultural plastic waste, not only on a large scale but also at local and regional levels [31, 32]. It is noteworthy that many of these processes and approaches offer benefits at local and regional scales, particularly in less-developed regions. They have the potential to instigate civil society and farmer movements aimed at collecting this plastic waste, thus significantly contributing to the reduction of terrestrial and aquatic pollution caused by its dispersion.

3.3 Agricultural Soil Remediation Strategies Towards Microplastics

In a recent review, Tian et al. comprehensively described the main sources of microplastics entering agricultural soil, including agricultural practices using plastics (mulching, greenhouses, etc.), the use of plastic carriers for seeds and fertilizers containing plastic, irrigation, and atmospheric deposition [33]. Once in the soil, microplastics undergo photo-degradation and mechanical abrasion and may interact chemically with other species, namely fertilizers, pesticides, and heavy metals. These interactions result in changes in the soil bulk and chemical properties, including pH, density and porosity and soil microbiome. Furthermore, when present in agricultural soils, microplastics may hamper agricultural productivity by delaying germination, reducing transpiration rates, and inhibiting plant root growth, posing potential threats to food security [34]. Besides the negative effects on soil, ecosystems and their services, there are also concerns regarding the possible exposure of humans to microplastics, through both food and water chains. A more in-depth knowledge is required, including long-term monitoring of soil key properties, evaluation of the effects of the exposure of soil and ecosystems to microplastics, and a systematic investigation of the composition and main characteristics of microplastics found in agricultural soils.

Addressing the pervasive issue of microplastics demands a comprehensive approach to mitigate their impact and facilitate remediation. Effective land management practices like reduced or no-till farming can restrict microplastics' spread, while incorporating organic matter or soil amendments such as activated carbon and biochar can limit their mobility [35]. Remediation strategies encompass physical, chemical, and biological methods, with biological approaches standing out for their environmental sustainability [36]. Microbial degradation, done by utilizing plastics as a carbon source, by bacteria, fungi, and actinomycetes, holds promise for breaking down plastics into biogas and biomass [35–37]. Ongoing research explores alternative methods, such as such as enzyme and membrane technologies, nanoparticle technology, and metagenomics, yet challenges persist in identifying microorganisms capable of targeting diverse plastics and high molecular weight polymers [35–37]. Considering site-specific conditions and monitoring effectiveness are crucial for successful remediation efforts.

In conclusion, the wide range of methods employed for microplastic remediation underscores the need for thorough consideration of site-specific conditions and remediation timelines. Monitoring is essential for evaluating the effectiveness of remediation efforts and assessing potential long-term consequences.

4 Integrated Approaches for Valorization of Plastic Waste – The Portuguese Context

The significance of an integrated approach involving polymer design, agricultural waste collection schemes, plastic waste valorization, soil remediation, and public policies promoting agricultural plastic waste collection and valorization cannot be overstated. Only through appropriate combination of these elements, can one effectively address the complex challenges posed by agricultural plastic waste (Fig. 2).

Fig. 2. Pillars for recycling and valorization of agricultural plastic waste

The first step for the integration of polymer design with waste management, recycling and valorization of agricultural plastic waste is the improvement of literacy amongst key stakeholders across different sectors and society in general. The increase in literacy on agricultural plastics shall serve to inform, lead to behavioral changes and catalyze new approaches for farmers, waste management players, recyclers and policy makers. Literacy improvement shall be done by different means (media, workshops, capacity building and knowledge transfer activities, etc.) in combination with the implementation of ready available online platforms, capable of enabling acquisition of information and knowledge at different levels, e.g. guidelines on appropriate segregation schemes for agricultural plastic waste, information of companies supporting/ executing collection schemes for agricultural plastic waste, central (community) locations for collection and storage of materials, waste management companies and recyclers already working with agricultural plastic waste and/or with potential (technical, economical). These online guidance platforms can also serve to guide farmers, waster management companies and recyclers on relevant political instruments (financial incentives, tax benefits, voluntary schemes, etc.) for collection and valorization of plastic waste. The availability of this information in the form of open sources through online digital platforms and the assurance of transparency is essential to better control and monitor the progress of any implemented strategies for agricultural plastic waste valorization at different points along the value chain.

Absence of voluntary collection schemes by farmers derives from the lack of knowledge on both value of the agricultural plastic waste and negative environmental effects of their inappropriate management. Dissemination and communication of knowledge on agricultural plastic wastes, training to farmers, civil society, waste management companies, local administration adaptation and policy makers is therefore, essential, to boost the interest, acceptance and acknowledgement of the value of valorization of agricultural plastic waste.

One important gap identified within the strategic plan for non-urban waste (PERNU), is the absence of a specific waste stream for agricultural plastic waste, lack of plans to monitor present and future volumes, as well as valorization quotas, associated with this type of plastic waste and, finally, absence of future measures and targets at different levels (e.g. collection, segregation, valorization). We believe that this exercise is essential in line with the expected raise of agricultural plastic usage, linked with the projected rise in the global population and required 60% food production by increase. Increased expected volumes of agricultural plastic waste shall drive consequently alternatives for governance and associated policies, stimulating the collection and valorization of these materials. As such the topic of waste generation and waste valorization for agriculture plastic emerges as a critical topic for which specific and targeted actions should be outlined. This approach can be easily integrated within the already existent framework of the strategic plan for non-urban waste (PERNU), the APA's National Waste Management Plan 2030 (PNGR 2030) and other relevant national strategies and plans, such as the Bioeconomy Strategy and the Carbon Neutrality Strategy, which also integrate literacy, capacity building and knowledge transfer, although, as previously stated only focused on packaging plastic waste and other residues.

Another important gap existent on both the PERNU strategy and the Portuguese Waste Management Plan for 2030 (PNGR 2030) has to do with the inexistence of clear distinction between plastic waste from agriculture and other plastic waste from other proveniences (e.g. packaging). This is in our view very critical mostly with the differences that these two types of wastes have with respect to the environment, in particular soil, water and biodiversity. In the absence of adequate collection and recycling schemes, due to the location where they are used and eventually unproperly disposed, agricultural plastic waste poses a much higher /direct threat and risk to the environment, than packaging materials. Non-recycled, non-valorized, mistreated agricultural plastic wastes are generally damped in the land, in the vicinity of plantations and farm areas, contaminating and damaging in very short-term, soil, water streams and biodiversity.

The Bioeconomy Strategy fails to consider agricultural plastic waste as a possible source for energy production and does not consider the potential of this waste for the development of other alternative business models, which, as previously mentioned are vast and diverse.

In this sense would be advisable that both PERNU and other relevant strategies would consider this type of waste separately, mostly given to its expected increased volumes, but also its valorization potential.

The adequacy of policy instruments aiming at an increase of agricultural plastic waste and valorization is pivotal and covers many different parts of the value chain (polymer design, agriculture activities, waste management and recycling).

The adaptation of policy frameworks at a polymer design and polymer processing level should mostly focus on the creation of solutions enabling longer lifetime, easier dismantling and improved recyclability of agricultural plastics. This should be done through adequate policies and instruments, setting for example a minimum thickness for specific agricultural films, guidelines for type and amount of specific additives targeting higher lifespan and incentives for dismantling, segregation and collection of waste. For the dismantling, segregation and collection of waste, in specific, policy instruments should be developed through a collective engagement and co-creation process involving multiple stakeholders (farmers, waste management companies and recyclers), addressing the specific requirements, challenges and opportunities (pains and gains) of these sectors. This approach shall provide more robust and adequate incentives (financial, fiscal, etc.) promoting a change of behavior towards agricultural plastic waste and the development and application of solutions for decommissioning, collection and recycling of agricultural plastic waste. A good example is the development of policies aiming at a promotion of waste segregation and separation of different types of agricultural plastic waste, in order to guide specific types of waste to specific new product target applications. For example, a film with low level of contamination that reaches its end-of-life should be segregated from a material with high contamination (soil, chemical contaminants, etc.) level. The recycling and valorization technology and the target properties of the final new products, for these two distinct types of waste are different. The information guiding the type of segregation required to maximize the valorization of agricultural plastics should be provided by recycling companies developing the new products and should serve to inform public policies and governance mechanisms, to be later implemented by farmers. Simultaneously, policy instruments should be available to subsidize the tracing and collection of these waste materials from the farms to waste management companies and from there to recyclers. In addition, fines should be implemented, for individuals not applying collection and recycling good practices and with non-environmental behavior (landfills disposal, burning, etc.). These schemes shall ensure that plastic waste generated during farming activities is properly collected and managed, preventing its accumulation in the environment.

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European Union Policy on Sustainable Rural Development: Challenges for Ukraine in Unstable Times

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Abstract. Ukraine has confidently embarked on the path of European integration, and before the Ukrainian State and society lies the task of implementing at the national level the reforms carried out within the framework of the Common Agricultural Policy. In other words, state intervention in agriculture and rural areas, following the European model, involves complementing support for the traditional function of the main activity of rural producers - the production of food products - with other dimensions of state policy, namely: sustainable rural development, spatial and landscape planning, combating climate change, diversification and revitalization of the rural economy, as well as sustainable production of energy and biomaterials. This work aims to show the perspectives and challenges that exist in the country in the process of implementing the national strategy for sustainable rural development.

Keywords: rural development · objectives · sustainability · war · risks · challenges

1 Introduction

In the process of changing perceptions regarding the significance of rural areas for society across various dimensions—social, economic, environmental, and political – that has taken place over the last two decades in the European continent [12–14], interest has also grown among researchers from other continents and countries. In Ukraine, the understanding of the increasing multifunctionality of rural areas and production practices encourages the development and deepening of new approaches to the interpretation of these concepts [8, 11, 15, 16].

Despite Russian aggression in eastern Ukraine, which began in early 2014, the country has begun a comprehensive process of reforms. Since 2015, the objective has been to implement social, economic and ecological transformations, as well as strengthening the democratic system through the promotion and dissemination of various public diplomacy actions by the European Union, in accordance with the international guidelines of the Sustainable Development Strategy. The transformative processes that took place during the last decade in the planned economic, social, ecological, and institutional dimensions, while yielding positive results in some socio-economic indicators, became impossible

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to implement in the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol, and parts of the Donetsk and Luhansk regions [8].

With the large-scale Russian aggression on February 24, 2022, which has been ongoing for almost two years across the entire territory of Ukraine, it is becoming increasingly challenging to monitor the implementation of sustainable development strategy goals using the methodology and indicator systems developed by the UN Commission in 2015 [10]. Beyond war, there are other factors within society that contribute to this issue. This difficulty is related to the lack of full participation from all sectors that should have been involved in the development, discussion, implementation, and dissemination of government public policies in local communities, especially in rural communities. In addition to the public sector, which creates, develops, and conveys national strategies in line with European guidelines, Ukraine still faces low participation and involvement from the private sector and civil society. This is in contrast to the European Union countries where such practices have already been well developed.

2 Common Agricultural Policy and the Concept of Sustainable Rural Development

The sustainable rural development policy was developed to address the challenges of the 21st century faced by the rural areas of European Union (EU) member states and EU candidate states. It is part of the Common Agricultural Policy (CAP), which is constantly refined and supplemented with new opportunities based on the economic, social, and environmental needs of European society.

One of the priorities of the EU's common agricultural policy for 2023–2027 is the creation of an effective model for supporting and promoting knowledge and innovation in agriculture and related areas: rural areas, value chains, environmental protection, climate change, conservation of biodiversity, sustainable development of society, etc. [3]. Ukraine is an active participant in the implementation of the system of transfer of knowledge and innovations in the agricultural sector (Agricultural Knowledge and Innovation Systems - AKIS) [4] at the regional level, as the rural population needs to increase its own level of awareness of potential opportunities and risks in conducting economic activities and understanding the rational use of resources. Dissemination of knowledge and practical skills on modern approaches to agricultural production and informational support for innovations in agriculture is important for small farmers to ensure the competitiveness and sustainable development of their activities [11].

It was planned that the strategic plans of the new CAP would be considered as benchmarks for achieving ambitious goals of sustainable development, now focused on rural areas, not just agricultural production, as outlined in documents such as i) the European Green Deal, ii) the "From Farm to Fork" strategy, iii) Biodiversity conservation strategy [2].

For the new CAP, which was implemented from January 1, 2023, the European Commission proposed using European Agricultural Fund for Rural Development (EAFRD) funding according to eight broad policy interventions, instead of the twenty general interventions used previously, thereby providing greater flexibility for EU countries to tailor policy measures to their specific needs.

The eight interventions to be considered when preparing projects are:

- Environmental, climate, and other management commitments;
- Natural or other specific constraints of the territory;
- Territory-specific shortcomings resulting from certain mandatory requirements;
- Investments;
- Involvement of young farmers and the opening of rural businesses;
- Risk management tools;
- Cooperation;
- Exchange of knowledge and information.

From the materials analyzed, it is clear that the new key elements of the CAP "will correspond to the new EU strategic program, which aims to integrate the global sustainable development goals (SDGs) of rural populations into areas in European cohesion policy." The changes are manifested in the introduction of one of the vital components of the agricultural sector and rural policy of the CAP, which has gained particular importance in recent years in EU countries. This involves support for so-called "public goods" or non-commercial functions of agricultural activity, which are not paid for by the market.

In Ukraine, in recent years, the creation of United Territorial Communities (UTCs) according to the European model has occurred, which has become a new paradigm of social innovation in national rural development policy. Innovative transformations have contributed to financing per unit area of agricultural land being directed towards investment in environmental measures and environmental protection programs. The manifestation of such changes in people's priorities can be seen in the examples of socially oriented European projects successfully implemented in rural areas before the war, related to the development of local bioenergy production, waste processing and recycling, social projects in the field youth employment, public organizations and other companies in the tertiary sector [17].

At the same time, at the international political level, there was a widespread popularization of the concept of a sustainable development strategy and the formation of international cooperation institutions and "the full recognition by the world community of the importance of sustainable development and the observance of principles of socially responsible behavior by society, the state and the business community" with the active participation of Ukraine as a full member country of the United Nations (UN) [16].

3 The Main Risk Factors for Sustainable Development Due to War

Russia's large-scale invasion and prolonged military aggression on the territory of Ukraine constitute the greatest and most dangerous risk factor for the sustainable development of the national economy, as well as for the equal and equitable development of the social sphere and the natural environment, not only in national society, but also throughout the world.

Damage and losses to Ukrainian agriculture are estimated at 40.2 billion US dollars, 78% of the total amount of the productive sector. War damage includes damage and destruction of production facilities, machinery and technical equipment, loss of income of agricultural holdings associated with a decrease in the volume or cessation of production, a decrease in prices for produced products, interruptions in logistical operations for exporting products, and the high cost of recovering affected lands after monitoring, cleaning and release [6, 9].

One of the main risk factors is the cessation and/or reduction of agricultural production. The decrease in the total number of companies engaged in agricultural production is 7.7%, of which 1% are animal breeders who have stopped partial production of plant products and 6.7% of agricultural companies who have completely stopped production [9]. The majority of companies (87%) that have halted production are located in frontline regions. It was also observed that the change in the structure of crops, the increase in the number of companies that grow vegetables and legumes can be understood as an attempt to diversify production as a result of restrictions on exports and income, as well as the change in production of perennial crops due to a significant labor shortage and, as a result, the closure of production. In agricultural enterprises in frontline regions, grain and oil crops (more than 10%), vegetables (3.2%) and pasture (3.6%) decreased the most [6].

A second important risk factor is the high percentage of land contaminated with unexploded ordnance. A total of 12% of companies were unable to use their land and cultivate it due to the presence of mines, bombs and debris, which represents approximately 9% of the total cultivated area. The analysis showed that according to the distribution of land contamination in the front-line regions, 98% of mined land was recorded, including 80% of which it was impossible to harvest. The survey results indicate that approximately 11% of agricultural enterprises were unable to harvest at least part of the crop in the contaminated area, which represents 4.5% of the total area of cultivated land. It is noted that areas cultivated with grain and oilseed crops were most affected by contamination, which corresponds to 96.7% of contaminated and unharvested areas, while the remainder are pastures and areas occupied by leguminous crops [9].

The third important risk factor is considered to be a sharp increase in production costs. It was observed in almost 93% of agricultural enterprises involved in crop production and was most visible in regions such as Cherkasy, Chernihiv, Chernivtsi, Dnipropetrovsk, Kherson, Kirovohrad and Zaporizhzhya, where more than 90% of agricultural enterprises reported significant or sharp growth. The analysis shows that compared to 2021, as a result of pollution of agricultural land, producers recorded an increase in production cost by 62%, and companies that were unable to partially harvest recorded an increase in production cost by 51.4% [6].

In livestock farming, an increase in production costs was observed in 76% of agricultural companies, of which more than half, or 60%, recorded a significant or sharp increase. The regions of Odesa, Sumy and Zhytomyr were the most affected, where more than 90% of enterprises in the livestock sector reported a significant or sharp increase in the cost of production.

As a result of the negative impact of the above-mentioned factors, a decrease in income from the sale of agricultural products was noted in almost 90% of enterprises, which are dedicated to crop production, compared to enterprises that are dedicated to animal production, where this indicator was observed at the level of more than 60%. Agricultural enterprises specializing in crop production and working in frontline regions are the most affected, which increases the likelihood of a 30% decrease in income compared to companies working in the western and central regions. The study indicates that there is an increasing probability of a 10% decrease in income in the agricultural sector, due to the fact that companies have difficulties in accessing agricultural resources, such as fertilizers, pesticides and seeds [6].

According to this study, it was observed that these factors influenced changes in operational decision-making by entrepreneurs in agricultural companies. Of these, almost 40% reported that because of the war they were forced to look for answers to solve problems and make new production decisions. Also, it was observed that this indicator was higher in the frontline regions and constitutes around 45%.

Among the reasons for making decisions about changes in production, the following stand out [6]:

- limited access to the purchase and use of agricultural resources;
- forced business diversification;
- search for other sales markets for production products created as a result of the large-scale Russian invasion.

4 Threats to the Fulfillment of Indicators of Sustainable Development Goals

The above-mentioned risk factors threaten firstly, the implementation of important global sustainable development goals (SDGs), such as SDG 2 – «Overcome hunger, development of agriculture», which in turn can affect the achievement of safety indicators food 2.1.1 – «Meat consumption» and 2.1.2 – «Consumption of milk and dairy products» per person (kg/year), which even before the war was characterized by a medium or low probability of achieving and, SDG 8 - «Decent work and economic growth» [5, 8].

Sustainable Development Goal 2 covers three main areas that are interrelated: i) access to balanced nutrition, ii) agricultural productivity and iii) food production. The Russian-Ukrainian war makes it impossible to improve the economic conditions of producers, taking into account that in these unstable conditions it becomes difficult to increase the productivity of the main factors of production - labor and land. Jean Fourastier (1971) defined the concept of technical progress and studied its economic consequences in several developed countries, relating it to the increase in production volume, obtained under the condition of a fixed quantity of raw materials or human labor. For the author, technical progress means "the increase in the speed with which a person masters difficulties, that is, the speed of action, which is expressed by another comfortable word: productivity" [7].

One of the important tasks of SDG 2 is to ensure the creation of sustainable food production systems, contributing to the preservation of ecosystems and the gradual improvement of the quality of land and soil, mainly through the use of innovative technologies. Monitoring of this task is done through sustainable development indicator 2.3.3. – the proportion of agricultural land under organic production, within the total area of agricultural land of Ukraine. In Ukraine, organic production began to develop in the early 2000s. In the period between 2015 and 2017 it had a decreasing dynamic, but from 2018 onwards the situation began to improve and in 2020 the expected target was achieved and constituted 1.1%, however, with a subsequent decreasing trend. According to data from the State Statistical Service of Ukraine, in 2022, the percentage of agricultural land in organic production in the total area of agricultural land was only 0.6% [8]. According to Rykovska, Fryer and Yarovoy (2023), the percentage of agricultural territories under organic farming in Poland in 2020 was 3.5%, in Bulgaria - 2.3% [1].

Labor productivity and population employment are important indicators for the sustainable development of agriculture. According to the definition of the Ministry of Economic Development, Trade and Agriculture of Ukraine, labor productivity is an indicator indicating the effectiveness of work, which characterizes the effectiveness of its costs in the production sphere, depending on the number of employed population. These indicators are used to monitor progress in implementing global SDG 8 – «Decent work and economic growth». The labor productivity change index indicates the fulfillment of task 8.3 – «Increasing production efficiency on the basis of sustainable development and the development of competitive high-tech industries».

The mentioned risk factors are likely to influence the growth of social inequality between the city and the countryside, which will make it even more difficult to achieve the indicators of other global goals, such as SDG 6 - «Clean water and adequate sanitation» and SDG 9 - «Industry, innovation and infrastructure», although all seventeen global goals of sustainable development are interconnected and affect, to one degree or another, the success in the implementation of others.

5 Some Conclusions

It is believed that it is impossible to reliably assess all the risks, because it is not known how long this war will last. But it is expedient to analyze the already inflicted damages in agriculture and their impact on changes in the economic, social, ecological and institutional systems of indicators of sustainable development from local to global levels in order to provide early conditions for solving existing problems and preventing their aggravation in the post-war period.

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Reshaping Africa's Sustainable Future Through 3D Printing

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Abstract. Africa faces a significant sustainable development crisis characterized by rapid urbanization, population growth, and poor housing conditions. Traditional construction methods usually do not support innovative technologies, resulting in housing shortage and inadequate home conditions. Construction 3D Printing emerges as a promising solution aligned with global initiatives for climate resilience and reduced ecological impact. This paper provides some insights on recent 3D printing technology advancements in African construction projects, with a focus on earth-based materials and sustainability. This work highlights the paradigm shift from traditional construction techniques to construction innovation driven 3DP solutions, particularly the potential to use earthen materials for 3D printing, this way boosting Africa's sustainable development, driving construction productivity and circularity. And ultimately fostering urban sustainable development and African living standards.

Keywords: Construction 3D Printing · Africa digital revolution · Urban Sustainable Development. Earth-based materials

1 Introduction

Africa stands as a well-equipped continent for economic development, supported by favourable factors for sustainable growth and prosperity (Ofori et al., 2023). Africa holds the foundation for a robust economic activity, with its abundant natural resources, including key minerals, fertile land, and renewable energy sources. The continent's rapidly growing population, characterized by an expanding youth demographic trend, represents an impressive workforce to drive innovation, entrepreneurship, and productivity. Coupled with a vibrant entrepreneurial spirit and a growing consumer market driven by a fast urbanization and expanding middle-class segments, Africa offers fertile ground for investment and business expansion (Gaglio et al., 2022). Promising efforts for infrastructure development, regional integration, and institutional reforms emphasize the commitment to creating a nurturing environment for economic growth. However, the African continent faces a persistent and complex housing crisis defined by a deficit in

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affordable housing, substandard living conditions in informal settlements, and a growing urban population. The housing dilemma on the continent underlines an urgent unease by the present slow construction processes, and significant waste, notably inside low-income housing population (Mahachi, 2021). Sadly, a deficiency in technical expertise and awareness on innovative construction methodologies has hampered the efficacy of African construction sector in tackling these difficulties.

Digital fabrication, aligned with Industry 4.0 practices, is pivotal for advancing the construction sector in Africa (Fahfouhi et al., 2023). Industry 4.0, often called the fourth industrial revolution, implies the integration of digital technologies, automation, and data exchange in manufacturing and other industries. In a comprehensive review of the adoption of 3D Printing (3DP) by the African construction sector, Moghayedi et al. (2024) stress the crucial role of 3DP as a sustainable building solution in Africa by optimising resource use, improving efficiency and productivity, and ensuring high precision in building performance. Furthermore, when coupled with 3DP technology, the automatisation of construction practices can significantly enhance the feasibility and effectiveness of using local earth-based materials for construction projects (Perrot et al., 2018). 3DP in construction offers a revolutionary approach, enabling the fabrication of building components layer by layer, reducing construction times and minimising material waste and labour costs (Ma et al., 2022). In a review on construction 3D printing in Africa, mainly in Morocco, South Africa, and Kenya, Fahfouhi et al. (2023) highlight the initiatives incorporating local earth-based materials, such as adobe or rammed earth, into 3DP processes aligned with sustainability principles, promoting economic empowerment within local communities. The benefits of this approach are comprehensive, including:

1. Reduced dependency on imported construction materials, thereby supporting local economies and fostering self-sufficiency;
2. Adopting earth-based materials reduces the environmental impact associated with traditional construction methods, contributing to Africa's efforts towards sustainable development;
3. Integration of robotics and 3DP technology enhances construction quality and efficiency, improving housing conditions and infrastructure across the continent.

The integration of 3DP into construction can assist in lessening Africa's housing crisis and rapid urban growth, as highlighted through various transformative initiatives across the continent. South Africa's MedAdd project, Nigeria's Stampar3D, and Togo's Woelab Lomé demonstrate the versatile application of additive manufacturing in addressing local challenges and fostering innovation. The implementation of projects like the University of Johannesburg's 3D Printed Houses and The Gambia's 3D Printing Farm, show the potential of 3DP to revolutionise traditional industries and create sustainable solutions for critical socio-economic needs (AfricaLive, 2024). Other initiatives, such as Metal Heart and Iroko by 14Trees, point out a concerted effort towards leveraging 3DP technology to drive economic development and social progress (Gadzala, 2018). Thus, embracing these innovative practices can represent a transformative opportunity for Africa's construction industry, driving economic growth while promoting environmental sustainability and social development.

There is an increased need to implement technological innovation into the building sector in the design and construction of affordable housing, mainly due to the persisting demands for adequate housing conditions and sustainable building solutions, there is an increased need to implement technological innovation into the building sector in the design and construction of affordable housing. Although the benefits of 3DP technology are apparent, its applicability and viability within the African context must yet be established. This paper seeks to explore the potential of 3DP technology in facilitating cost-effective housing solutions in Africa, assessing its practicality regarding traditional construction techniques.

2 Affordable Housing Crisis in Africa

Rising interest rates and the pandemia hampered house affordability worldwide, African Housing crisis and affordability challenges are a prevalent global issue, as rising interest rates and the pandemia hampered housing affordability worldwide.

However, as abovementioned, Africa faces unique circumstances shaped by rapid urbanisation, fast population growth, and economic disparities. According to the UN-Habitat, the continent's urbanisation rate increased from 15% in 1960 to 40% in 2010, and it is expected to reach 60% by 2050, deeply reshaping its landscape. This exponential urban increase is set to triple Africa's urban populations over the next 50 years, amplifying the demand for affordable housing (UN-Habitat, 2023). The Centre for Affordable Housing Finance in Africa (CAHF) reports 85% of African nations are facing significant affordability challenges, particularly impacting low-income urban households. Despite governmental efforts and international support, as the ones outlined by Agenda 2063, aiming to transform Africa into a global powerhouse of the future, the continent deals with a substantial deficit of at least 51 million affordable housing units (Moghayedi et al., 2024). This deficit, coupled with prevailing issues, such as informal settlements and substandard living conditions, highlights an urgent need for effective strategies and interventions to address Africa's housing crisis.

Today, these huge challenges persist despite the implementation of various affordable housing schemes and subsidies, slow delivery processes due to financial constraints and the lack of digitalisation and innovation in construction practices (Fahfouhi et al., 2024). To overcome these barriers, there's a growing need to integrate new locally available materials and innovative construction technologies to enhance the quality, efficiency, and sustainability of housing solutions across Africa. This shift toward sustainable and environmentally conscious practices aligns with global initiatives, representing a fundamental step toward addressing the pressing housing needs for Africa's swiftly expanding urban population. In The African Development Bank's report called "Promoting affordable housing in African Cities", there is a thorough investigation on housing crisis challenges in Nigeria, Cameroon, and Zambia, where most households are in inadequate conditions according to the SDG 11 definition. Figure 1 shows the percentage of households in poor conditions.

Most urban households, particularly those classified as low-income, lack the financial resources to get newly built houses provided by the private sector, even if they are inexpensive, even when mortgage funding options are available. There is an urgent need for comprehensive strategies to address this affordability gap, ensuring that large amounts of population can access suitable housing solutions, reducing this way the impact of rapid urbanisation on house prices and affordability.

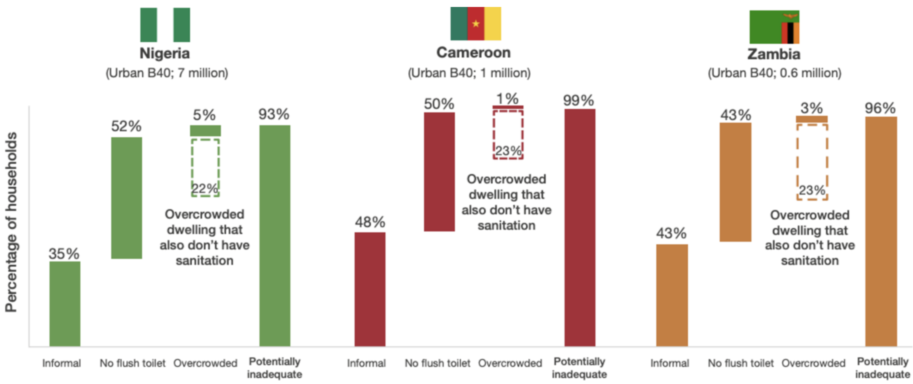

Fig. 1. Housing conditions among the bottom 40th percentile in urban Nigeria, Cameroon, and Zambia, adapted from (African Development Bank, 2023).

Figure 2 shows the proportion of householders who can afford the cheapest newly built homes by private contractors.

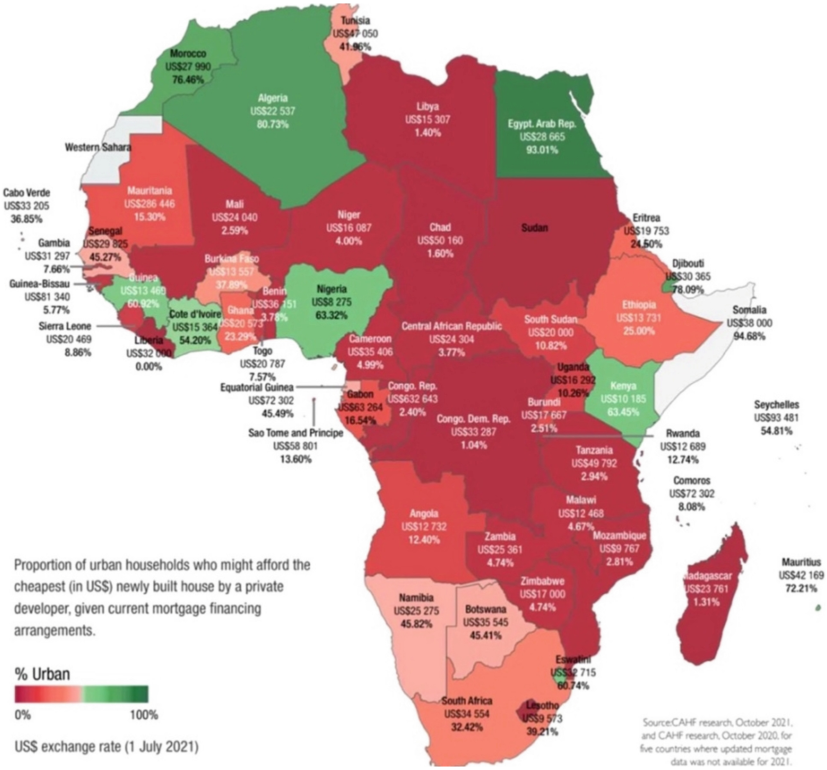

Fig. 2. Percentage of affordability of cheapest newly built houses in African countries, adapted by CAHF (2021)

There are other complex challenges in Africa to overcome, such as the link between poverty and conflict, which, combined with the affordability crisis, results in a significant shortfall in government-provided affordable housing. Recent data suggests an alarming deficit of at least 51 million affordable housing units across the continent (CAHF, 2023). Nigeria bears a substantial burden with a housing deficit of 28 million units, while the Democratic Republic of Congo faces an estimated shortage of 3.9 million, requiring the construction of over 260 thousand housing units annually. Similarly, South Africa struggles with an affordable housing shortage of approximately 3.7 million units.

Despite the implementation of several national and international housing schemes in Africa, the housing crisis persists, largely due to financial limitations and a slow delivery process. These challenges arise primarily from the absence of digitalisation and innovation in planning, design, and construction practices (Moghayedi et al., 2022). Incorporating alternative new local materials and modern construction methodologies is crucial for solving affordable housing problems. It will also help mitigate housing conditions while reducing waste and accidents. This can be a paradigm shift aligned with global initiatives for climate resilience.

3 3D Printing for the Housing Sector in Africa

In recent years, Africa has been at the forefront regarding technological innovation in the housing sector, which comes from the urgent need to mitigate complex construction challenges. Many African governments, including Kenya, Nigeria, South Africa, and Ghana, have stressed the importance of using innovation to speed up housing delivery while improving quality and efficiency (Mahachi, 2021). Conversely, the construction sector has been criticised for its environmental impactful activities that result in material waste, misuse of natural resources, and huge amounts of waste, this way impeding the fulfilment of the Sustainable Development Goals (SDG) (Ogunmakinde et al., 2022). Franco et al. (2022) argue that it is important to recognise that the civil construction sector faces numerous challenges in maintaining its operations and, as a result, in achieving sustainable development goals, as the construction production chain has a significant impact on the three pillars of sustainability. According to the Mckinsey Global Institute Industry Digitization Index (Agarwal et al., 2016), construction remains one of the least digitalised and innovative industries in terms of the implementation of Industry 4.0 technologies.

Digital processes allow not only optimising the use of resources (energy and materials) and waste but also the incorporation of recycled materials for 3D deposition (Tahmasebinia et al., 2020). Table 1 shows selected Industry 4.0 technologies (Advances in Materials, 3D Printing, and BIM) impacts in the Triple Bottom Line.

Fahfouhi et al. (2023) point out the use of earth-based materials in Morocco, Tunisia, and Algeria, where houses were built for centuries using earthen materials and traditional construction techniques, ranging from rammed earth to cob houses, which hold a great architectural heritage and culture. Using raw earth, a local natural material, for digital constructions dates back to 2004, when Khoshnevis (Khoshnevis, 2004) investigated the contour crafting technology for houses that could be automatically built with 3DP technologies, using only local materials. Other similar works, such as (Craveiro et al., 2018; Curth et al., 2024; Faleschini et al., 2023; Tarhan & Perrot, 2023; Fahfouhi et al., 2022), also have used more environmentally friendly 3DP construction material formulations.

Table 1. Industry 4.0 impacts on social, economic, and environmental sustainability (adapted from Franco et al., 2022).

Industry 4.0 Technologies	Triple Bottom Line		
	Social	Economic	Environmental
Advances in Materials	Income generation for construction waste recycling plants and employees	Beneficial use of solid waste technological treatment and saving of natural resources	
3D Printing	Low-income housing	Mass customisation and fast implementation reducing construction costs due to less waste	Optimisation of resources and waste management
Building Information Modelling (BIM)	Monitoring health and safety issues – reduction of work accidents	Increase the productivity and efficiency of operations and processes and improve the quality of projects	Improve energy performance; CO2 emissions; resource efficiency and waste management; air quality
Digital Twin	Facilities management by improving societal quality of life following the principles of sustainability	Digital Twin can be used to learn and suggest new scenarios before building a product and planning for development with better management of time, quality, and natural resources	

Currently, the use of earth-based materials for digital fabrication by 3DP technologies has been growing worldwide, while some earth-based composites have been developed. The utilisation of digital fabrication techniques together with earth-based materials is currently undergoing a rapid transformation within the construction industry. The precision of digital fabrication allows consistent quality and structural integrity of earth-based components, mitigating concerns on its variability (Zaid & El Ouni, 2024). The adoption of digital fabrication for earth construction has been supported by advances in material science and sustainable practices (Gomaa et al., 2022). Researchers have been investigating ways to optimise earth-based materials for 3DP, enhancing its strength and durability while minimising environmental impact, sometimes incorporating recycled materials or integrating natural fibers into the earth mixture.

WASP most well-known projects are Gaia and Tecla House (WASP, 2023). These projects include printing houses using only sustainable and recyclable construction materials, mainly earth. These projects were carried out in collaboration with RiceHouse, an enterprise specialising in sustainable construction using rice production waste, for the construction of Gaia (Fig. 3a). Gaia represents a significant milestone as it is the first sustainable housing model created from earth-based materials, sourced from locally available materials and natural by-products from rice cultivation. This innovative project aimed to achieve an efficient, bio-climatic building, considering ecological factors. Gaia's construction involved a unique composite, incorporating 25% on-site soil (comprising 30% sand, 30% clay, and 40% silt), 25% rice husk, 40% straw derived from rice, and 10% hydraulic lime (Chiusoli, 2018). Tecla House (Fig. 3b), a fusion of "Technology" and "Clay," stands as a groundbreaking circular housing model entirely made by 3D-printed from locally sourced, reusable, and recyclable materials.

a) b)

Fig. 3. WASP projects: a) Gaia Project, and b) Tecla House (WASP, 2023).

4 Conclusions

Africa's economic transformation is progressing fast, new opportunities are thriving for a talented young population and a booming digital revolution, despite the negative impacts of rapid urbanization and climate change.

This paper highlights the importance of coupling earthen materials with 3DP technologies to promote its wider adoption by the construction sector for delivering sustainable and affordable housing in Africa. To support this transition, it is crucial to systematically evaluate the current building performance and costs in the African context, offering valuable insights into the practical challenges and advantages of this Additive Manufacturing technology.

3DP technology holds immense potential to address Africa's affordable housing crisis for a rapid urban population growth. By adopting 3DP, Africa can overcome challenges related to affordability, quality, and sustainability in housing construction. This AM technology offers a transformative solution, allowing for an efficient utilization of local materials, increasing safety, reducing waste and resource consumption, and enabling faster construction processes. Moreover, 3DP aligns with global initiatives for climate resilience and sustainable development. Even though benefits of 3DP are apparent, its widespread adoption in Africa requires further research, investment, and collaboration among governments, industries, and academia. Despite the challenges ahead, embracing innovative practices like 3DP represents a critical step towards building resilience and inclusive communities across the continent. Ultimately, the integration of 3DP technology has the potential to revolutionize the construction industry in Africa, driving economic growth, environmental sustainability, and social progress.

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Physical Properties of Earth-Based Materials Stabilised with Biopolymer Binder

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Abstract. The use of cement-based building materials in the construction sector has become widespread, leading to a rise in carbon footprint and costs. This has created a need for sustainable construction to address the environmental impact. In recent years, researchers have renewed their focus on natural earth-based materials used in earlier eras because of their environmentally friendly and economical properties. However, the low mechanical properties of these materials underline the need for stabilisation. Therefore, to address the environmental impact of synthetic materials, there has been an increased focus on improving the mechanical properties of these materials with materials of biological origin. The aim of this research was to examine the physical properties of a mixture of earth materials with varying concentrations of guar gum (0%, 0.1%, 1%, and 5%). In this study, physical parameters such as unit volume weight, flow table test, air content, and penetration depth in the fresh state, as well as flexural and compressive strength tests in the hardened state, were conducted. The objective of this research is to determine the suitable usage rates of biopolymers and to provide insight into the future use of bio-stabilised earth-based materials.

Keywords: Earth-based materials · Stabilization · Guar gum · Physical properties

1 Introduction

The construction industry faces the dual challenge of minimising environmental impact while meeting the growing demands for infrastructure development in the quest for sustainable construction practices (Akadiri et al. 2012). Concrete and asphalt are traditional construction materials that offer strength and durability. However, they come at a significant environmental cost due to high carbon emissions and extensive resource depletion (Horvath 2004). As a result, there is growing interest in alternative materials that are not only environmentally friendly but also economically viable and technically feasible.

Raw earth is one of the oldest building materials in the world. Earth-based construction materials have recently gained renewed attention as a sustainable alternative to

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conventional building materials (Pacheco-Torgal and Jalali 2012). These materials are derived from natural soil, offering advantages such as a low carbon footprint (Ventura et al. 2022), local availability (Nwaki and Eze 2022), and recyclability (Parlato et al. 2021). However, its broader adoption in modern construction is often limited mainly due to its lower strength and susceptibility to water damage (Zhang et al. 2024).

Biopolymers are the preferred choice as binders for earth-based materials, as they are natural materials derived from plants, animals and micro-organisms, so with a low environmental impact, though contributing to its strength (Laborel-Préneron et al. 2018). This stabilisation method aims to reduce the environmental impact while enhancing the strength of earthen materials. There are several examples from the literature. In a study by Ghasemzadeh et al. (2022), calcium chloride was used as an ionic crosslinker to enhance Iranian gum biopolymer. Tests were performed on soil stabilised with xanthan gum, a common hydrocolloid for soil stabilisation. It was found that the cross-linked hydrogel (about 201.1%) showed a superior compressive strength increase and stronger reinforcement performance than xanthan gum (83.5%). Ramdas et al. (2021) carried out an overview of soil stabilisation techniques, the primary challenge for future research in bio-based stabilisation products application in the road sector, and innovation to address the use of modernised techniques in the road construction industry (Kabakuş and Tarhan 2023). These innovations include the development of potential bio-based additives for unpaved road construction applications, addressing weak subgrade and the required maintenance. Kavazanjian et al. (2009) investigate the effectiveness of biopolymers for erosion control and soil stabilisation. The results show that biopolymers can reduce the risk of erosion by improving soil aggregates, which suggests that biopolymers have potential for soil stabilisation, particularly in the areas prone to erosion.

This paper examines the potential of earth-based materials stabilised with biopolymers in construction, focusing on low-strength applications such as pavements, pathways, and low-load-bearing structures. By combining biopolymer science with traditional earth construction techniques, we aim to create sustainable construction materials. This approach contributes to reducing the environmental impact associated with construction activities and creates opportunities for innovative, eco-friendly construction practices.

2 Material Method

Various soil types were used in the composition of the soil-based mixture, as shown in Fig. 1. Organic soil obtained from agricultural fields, with a unit volume weight of 0.9 g/cm3 (Fig. 1a), was used with a particle size of 0–2 mm. The unit volume weight of fine-grained sand (Fig. 1b) is 2.47 g/cm3, and particle sizes are within the range of 0–2 mm. In addition, the Atterberg limits of the red clay, used as a binding agent in the mixture (Fig. 1c), were determined as 80% liquid limit, 31% plastic limit and 49% plasticity index. According to the Unified Soil Classification System (USCS), this clay is defined as CH, so it is a high-plasticity clay.

Biopolymers are naturally occurring organic polymers, less harmful to the environment than petroleum-based material ones (Van De Velde and Kiekens 2002). Its environmental impact is reduced, as they are biodegradable and derived from renewable

a b c

Fig. 1. Raw-Earth types used for the earth-based mixture.

resources. Thus, biopolymers are considered an environmentally friendly alternative in terms of sustainability. Guar gum (GG), a type of biopolymer, is derived from the seeds of the guar plant, scientifically known as Cyamopsis tetragonoloba (Sulaiman et al. 2022). Physical and chemical properties of guar gum: Molecular mass = 535.15 g/mol, viscosity = 5800 mPa.s, pH = 6.50, grain size = 200 mesh, E number = E412, form = powder. GG was used in this work due to its lower cost than other biopolymers. The ratios of the materials used in soil-based mixtures are given in Table 1.

Table 1. Mixture designs.

	Material Amounts (%)				
Mixture	Organic Earth	Sand	Red Mud	Water	Biopolymer
GG-0	40	30	30	14	0
GG-5	40	30	25	41.6	5
GG-1	40	30	29	36.6	1
GG-0.1	40	30	29.9	25	0.1

GG was first mixed with distilled water at 1000 rpm in a mechanical mixer until dissolved. Soil materials in the proportions indicated in Table 1 were dry-mixed in a laboratory mortar mixer at 60 rpm for 1 min. Water with GG was then added and mixed again for 1 min. After 1 min of rest, the mixture was then mixed at 120 rpm for a further 2 min and placed in cube and beam moulds by the tamping method. These three mixtures with different GG ratios were placed in the moulds and dried in the laboratory (21 ± 2 °C) for one day and then in an oven at 60 °C for one more day. The first two blends, GG-5 and GG-1, stuck to the moulds, expanded and swelled during the moulding process, and could not be demoulded. All mixtures were subjected to fresh state tests (unit volume weight, air content, flow table spreading diameter and penetration depth) and cured indoors at 23 ± 2 °C for 28 days. After 28 days, the flexural strength and compressive strength of GG-0.1 samples were evaluated.

In order to determine the optimum biopolymer ratio for the earth-based blend, firstly, 5% and 1% GG were used, but the obtained mixtures did not adequately harden at the end of the moulding period, blistering and cracks were formed on the upper surface, so it could not be removed from the mould (Fig. 2). Thus, a suitable biopolymer mixture was obtained for this earth-based mixture by using 0.1% GG, as the biopolymer ratio and experimental studies were carried out on these samples.

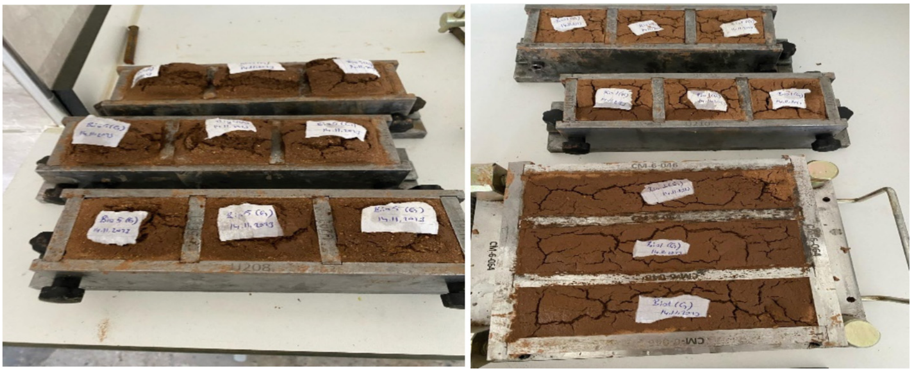

Fig. 2. GG-5 and GG-1 specimens, where GG was used in high proportions, swelled while waiting in the mould.

3 Results

Several tests were carried out, such as unit volume weight, air content, spreading diameter and penetration depth, to evaluate the properties of the earth-based mixtures. The mechanical performance of the mix was evaluated by determining the flexural and compressive strength of the cured samples. The fresh state results are presented in Table 2.

Table 2. Fresh state experimental results.

Group	Unit weight (g/cm^3)	Flow table (cm)	Cone penetration depth (mm)	Air content (%)
GG-0	1.859	12	10.5	1.7
GG-5	1.482	11	7.1	2.5
GG-1	1.604	10.5	14.3	2
GG-0.1	1.720	11.5	12.3	1.6

Table 2 clearly shows an inverse relationship between unit volume weight and air content. In other words, it can be observed that the density per unit volume decreases in parallel with the increase in air content. To enable a better understanding of Table 2 experimental results, these results are graphically displayed in Fig. 3.

The workability of the mixture was determined using cone penetration depth and flow table tests. As shown in Fig. 3, while the unit weight, air content and flow table

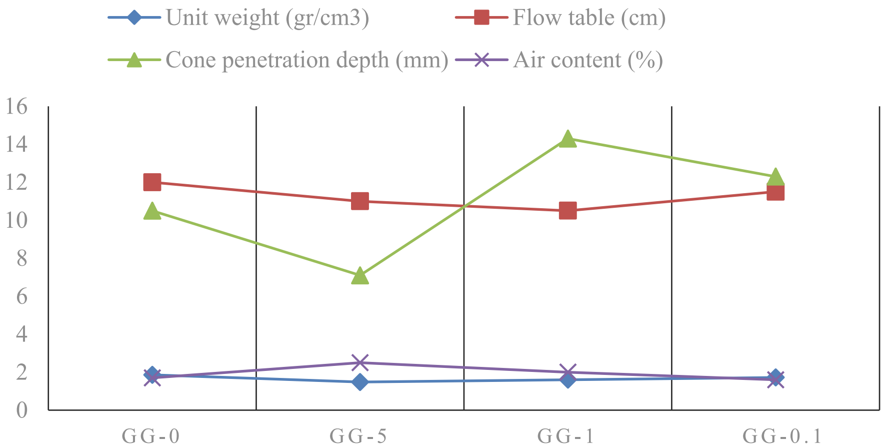

Fig. 3. The results of fresh state tests.

test of all group results are close to each other, the cone penetration results are quite different. Adding 5% GG to the mix reduces the penetration depth, so creating a more compact mix. Reducing the amount of GG to 1% reduces the consistency density. 0.1% GG enables a more workable consistency. Increasing the proportions of GG, led to a decrease in the flow diameter of the mixture. Incorporation of GG into the earth-based mix increases the viscosity of the mix, leading to a reduction in the penetration depth. The increase in viscosity is probably due to the interaction of the GG with water, resulting in a gel-like consistency and a more consistent structure.

The mechanical strength of the earth-based cured mixes is illustrated in Table 3. When compared to the strength of GG-0 and GG-0,1 mixes, It was observed that adding GG to the earth-based mix reduced its strength. Due to the lack of strong bonds between the soil components and the selected biopolymer GG to increase strength, it was decided that GG was not an acceptable stabiliser for this mix.

Table 3. Hardened state test results.

Group	Flexural Strength (MPa)	Comp. Str.(MPa) 28 day
GG-0	1.022	1.66
GG-0.1	0.804	1.304

4 Conclusion

In this ongoing work, a series of experiments were carried out to investigate the properties and mechanical performance of earth-based mixtures, with particular emphasis on the effect of adding guar gum (GG) at various concentrations. The experiments, which included tests for unit volume weight, air content, flow diameter and penetration depth, were designed to assess the workability and density of the mixtures. Mechanical strength was assessed by flexural and compressive strength tests on cured samples.

The results showed an inverse relationship between unit volume weight and air content, indicating that an increase in air content results in a decrease in density. Workability tests, including cone penetration and flow table tests, showed that adding 5% GG, resulted in a more compact mix with reduced penetration, while reducing GG to 1% decreases the consistency density of the mix. The lowest GG concentration tested, 0.1%, provided a more workable consistency, but increasing GG levels reduced the flow diameter, suggesting that GG incorporation increases the viscosity of the mix and reduces the penetration depth, due to its interaction with water, creating a gel-like consistency.

Biopolymers have a wide range of applications in various industrial sectors, such as agriculture, food, textiles, pharmaceuticals, cosmetics and construction, due to their diversity and properties, as they provide sustainable and environmentally friendly solutions. They can contribute to the reduction of many environmentally harmful materials in the industry, by integrating them in building materials and soil improvement, especially in the construction sector. However, in this study, GG was added to the earth-based mixture, consisting of natural materials, not showing the expected stabilization effect. It is a sustainable material, though its use is not recommended for earth-based mixtures, mainly due to its adverse effects in the compressive and flexural strength, reducing the strength of the mixture. Future studies will investigate the effects of different GG percentages, different water contents and different biopolymer types on the mechanical properties of earth-based mixtures.

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Influence of the Addition of a Green Roof in the Seismic Performance of an Existing Steel Building

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Abstract. The addition of a green roof to existing multistorey buildings in urban areas is a particularly interesting environmental upgrading solution, promoting sustainability, but it changes their seismic performance. In this study, the influence of adding an extensive green roof to a six storey office building, with steel structure, is assessed using a pushover procedure. The capacity curves required by this procedure were computed with the structural analysis software EvalS. The choice for an extensive green roof, instead of an intensive one, is justified, since i) it is more likely to be adopted in existing buildings and ii) it may avoid having to strengthen of the structure. The pushover procedure – seismic nonlinear static analysis – is one of the possibilities proposed by the Eurocodes to evaluate the seismic performance of buildings.

Keywords: Green roof · Sustainability · Steel building · Seismic Analysis · Pushover analysis

1 Introduction

The addition of a green roof (GR) to multistorey buildings in urban areas is an environmental upgrading solution, promoting sustainability. A comprehensive review of the advantages and disadvantages of such solution is presented in [1].

As mentioned in [1], the adoption of GR in existing buildings changes their seismic performance. On the one hand, adding a substantial mass to the top of a building can significantly increase its flexibility, affecting its dynamic proprieties, e.g., reducing its natural frequencies.

Ongoing studies [2, 3] show that GR increase the seismic energy dissipation capacity of buildings. However, it must be noticed that the Eurocodes – the European codes for the design of buildings, see [4, 5] – do not allow to take into account this favourable effect in the design.

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The reduction of the natural frequencies is, at first glance, favourable since it often means a decrease in the building seismic accelerations. However, for existing buildings, it can also increase the inertial forces and decrease their earthquake resisting capacity.

In this study the influence of the addition of a GR to a six storey office building with steel structure, presented in [6] and [7], is assessed. The pushover procedure – seismic nonlinear static analysis, see [8] and [6] – is one of the possibilities proposed by the Eurocodes to evaluate the seismic performance of buildings. The required capacity curves were computed with the software for structural analysis EvalS [9]. The choice for an extensive GR, instead of an intensive one, see [1], is justified, since i) it is more likely to be adopted in existing buildings and ii) it may avoid having to strengthen the structure. According to [2], the weight of an extensive GR varies between 0,7 kN/m^2 and 1,7 kN/m^2, the last value having been adopted in this study.

2 Seismic Performance and *Pushover* Analysis – A Brief Overview

The *pushover* methods are procedures for determining the seismic performance of buildings, that are based on a very simple notion: it is assumed that the effective seismic performance of the structure can be determined by *comparing* the seismic *demand* on the building, expressed through a response spectrum, see [8], with the structural *capacity* of the building.

This *capacity* is assessed by measuring the increasing horizontal displacement d of a control node, on the roof of the building, caused by a horizontal load pattern, proportional to the first vibration mode of the structure, simulating the inertial forces. The magnitude of this horizontal load pattern (and the corresponding base shear F at the foundation level) is monotonically increased (it may have to be decreased after a maximum) from zero up to the value corresponding to the potential collapse of the structure, defining a capacity curve, see Fig. 1. This *capacity* curve reflects the nonlinear behaviour of the structural materials and the second order effects, fully defining the seismic structural performance of the building. In order to permit the comparison with the response spectrum this *capacity* curve is converted into that of an equivalent single-degree-of-freedom (SDOF) system (quantities denoted with the symbol*) with mass m^* that undergoes a displacement d^* under the applied force F^* see Fig. 2. This SDOF has a natural frequency, to which, according to the response spectrum approach, corresponds a *demand,* i.e., the maximum acceleration and displacement induced by the design seismic event. The intersection of the capacity curve and demand spectrum defines the target displacement d_t^* of the SDOF system and, by inversion of the previous conversion, the corresponding target displacement d_t of the control node (of the effective structure), to which corresponds the magnitude of the horizontal forces used to assess the global seismic behaviour of the structure, see Fig. 1. Besides the above horizontal modal pattern, pushover methods also require the consideration of the effect of a uniform horizontal load pattern, simulating a *soft-storey* failure, see Fig. 2. This study employs the N2 method, proposed in EN 1998-1, but the details will be omitted. All the presented capacity curves and related results concern the full model of the structure.

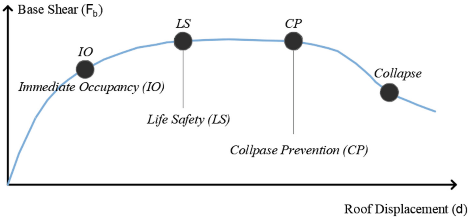

Fig. 1. Capacity Curve (from [10], p. 12).

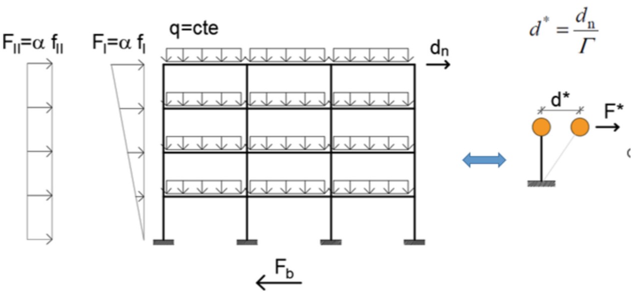

Fig. 2. Schematic representation of the full system, with the gravity load and the two horizontal load patterns (left), and of the equivalent SDOF system (right).

3 Building Description and Actions

The six storey office building adopted for this study, was established in [6]. The ground floor is 4.0 m high and the upper floors are 3.5 m. The building's structure is formed by two sets of orthogonal steel portal frames and composite slabs. Figure 3 depicts the structural plan of a typical floor, indicating in bold lines the location of the primary moment resisting frames (MRFs). Figure 4 shows the MRF configuration in the two main plan directions, and the member sections. The steel grade is S235. The slabs were designed to resist vertical loads and to behave as horizontal rigid diaphragms. The column foundations were assumed to correspond to clamped supports. Table 1 presents the seismic weight of each floor, see [6], i.e., the gravity loads applied to each floor when assessing the seismic capacity of the building, with and without the green roof (GR). This gravity loading is kept fixed in the pushover analysis. The two sets of values only differ in the top floor, due to the GR weight, 1,7 kN/m^2. The total weight is 24,9MN without the GR and 27,5MN with the GR, representing a 10% increase.

Table 2 presents the relevant seismic action parameters (response spectrum approach), including the soil parameter S and the importance factor. Only the Type I seismic action, EN 1998-1, and the horizontal direction X were considered in the present study. The considered reference peak ground acceleration a_{gr} is 0,25g ($g = 9.8$ m/s^2).

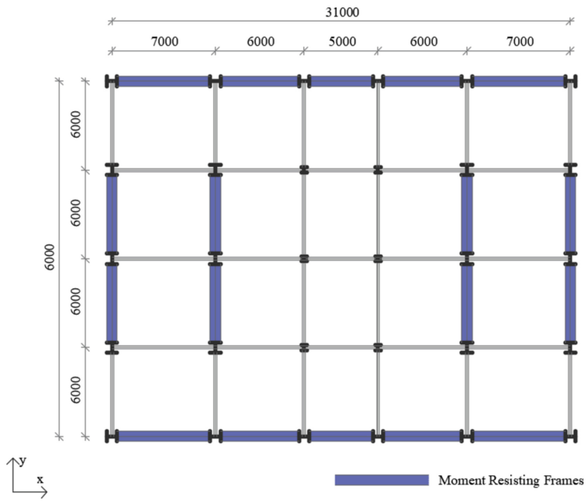

Fig. 3. Structural plan of a typical floor (from [6], p. 287).

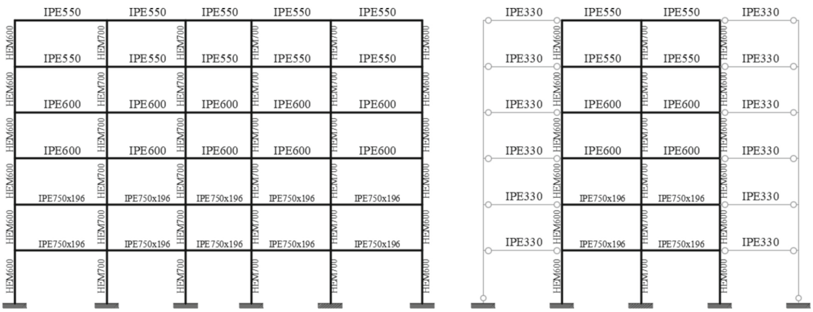

Fig. 4. MRF configuration and cross-sections: direction a) X and b) in Y (from [6], p. 287).

Table 1. Seismic weight (kN/m2) of the building floors.

floor	1	2	3	4	5	6 (roof)
w/o green roof	5.83	5.75	5.73	5.69	5.69	4.81
with green roof	5.83	5.75	5.73	5.69	5.69	8.21

4 Capacity Curves – Modelling Assumptions

4.1 Global Model – 2D Approach

To compute the capacity curve of the building, a structural model is created which considers the steel nonlinear behaviour and the second order effects, corresponding to the gravity loads acting on the deformed configuration of the structure. Because of the high regularity of the building both in plan and in elevation, 2D models can be used.

Table 2. Spectral characterization of the Type I seismic action employed in the analysis.

a_{gR}	γ_I	a_g	S	T_B	T_C	T_D	η
(m/s2)	-	(m/s2)	-	s	s	s	-
2.4525	1.0	2.4525	1.15	0.2	0.6	2	1

The structure presents two identical exterior MRF in direction X, with influence length of 3,0 m, and three additional inner gravity frames (not part of the primary seismic force resisting system), with influence length of 6,0 m. These influence lengths determine the gravity loads supported by each of the 5 frames, according to the seismic weights in Table 1. To account for the second order effects, a *leaning-column* was modelled for the seismic weight supported by the gravity frames, as suggested by Landolfo [6], see Fig. 5. The capacity curve of these MRFs was computed using EvalS [9].

4.2 Material Nonlinear Behaviour - Distributed Plasticity Approach

The plastic hinge approach was adopted in [6] to model the nonlinear behaviour of the steel members: they are modelled as linear elastic and a nonlinear spring is added at the end sections (critical sections), to simulate the plastic behaviour. In [6], the simplified bending moment-rotation relationship represented in Fig. 6a was employed, with a total plastic rotation $a = \theta_C - \theta_y = 9\ \theta_y$, where θ_C is associated to the ultimate capacity corresponding to point C and θ_y is the rotation at yielding. If the brittle modes are fully avoided, the ultimate seismic capacity of a portal frame (last point of the capacity curve) is theoretically reached when point C is first reached in any critical section, i.e., $\theta = \theta_C$.

Figure 6b represents the three limit states considered when assessing existing structures, given in the Eurocodes (EN 1998–3): i) Damage Limitation (DL), which permits the immediate occupation after the seismic event; ii) Significant Damage (SD), where the structural damage is significant, but the residual strength is enough to resist possible additional earthquakes and iii) Near Collapse (NC), when the collapse of the building is close, but not yet reached.

Table 3 presents the quantification of these limit states at the level of the critical sections (EN 1998-3, section B.5.2), as employed in [6]. Following [6], only the Severe Damage (SD) limit state will be considered in this study.

Instead of the plastic hinge approach, in this study, a distributed plasticity approach was adopted to model the nonlinear behaviour of the steel members, with the nonlinear elastic-plastic relationship of steel explicitly modelled at the fibre level. The employed bilinear stress strain constitutive law is defined by the parameters presented in Table 4 (E2 is the post yielding stiffness). The overstrength factor is defined by Fajfar [11] “at the level of the whole structure, as the ratio between the actual strength and the code prescribed strength demand arising from the application of prescribed loads and forces”, the value $\gamma_{ov} = 1{,}25$ having been used [6]. In this model, the ultimate capacity of any section corresponds to the ultimate curvature (point C in Fig. 6), see Table 5

$$\chi_C = \theta_C / L_s = 10\,\theta_y / L_s \qquad (1)$$

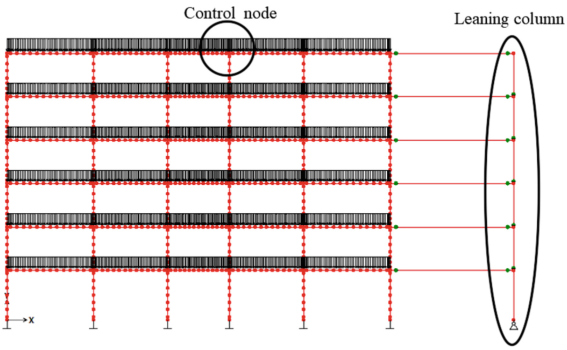

Fig. 5. Structural model of the investigated MRF created in EvalS for generating the capacity curve.

where L_s is the equivalent plastic hinge length, whose value was fixed as the depth of the structural element. Several *frameworks* have been implemented in EvalS for tackling the nonlinear problem, see for instance [12]. In this study, the Fictitious Force Method was applied, see [13, 14]. Figure 5 presents the employed finite element mesh, with the beams and columns were divided into 14 and 8, respectively, Euler-Bernoulli finite elements. The cross-section of the beams and columns was divided into 60 fibres, as required in the fibre model approach used, see [13].

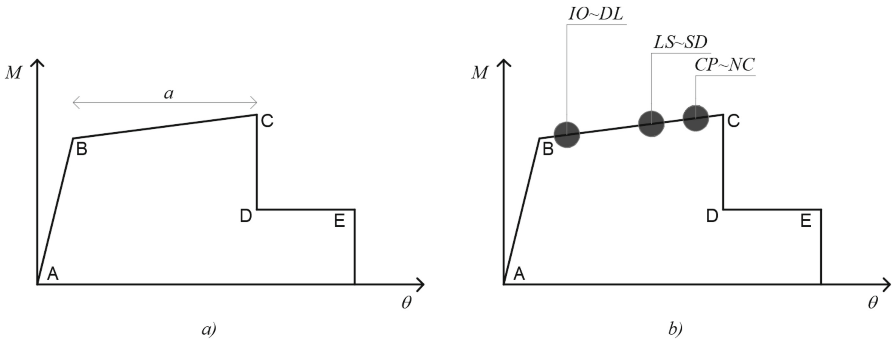

Fig. 6. a) Nonlinear moment-rotation relationship and b) acceptance criteria ([6], p. 323; IO, LS and CP are the performance limits in FEMA 356 [15], corresponding to the limit states DL, SD and NC in EN 1998–3).

Table 3. Plastic rotation defining the limit states at the critical sections (EN 1998–3, B.5.2).

Limit State		
DL	SD	NC
$1\ \theta_y$	$6\ \theta_y$	$8\ \theta_y$

Table 4. Nonlinear constitutive parameters of steel.

steel grade	f_y	γ_{ov}	$f_y \cdot \gamma_{ov}$	E	E2 = 0,03E
	[MPa]		[MPa]	[GPa]	[GPa]
S235	235	1.25	294	210	6.3

Table 5. Ultimate rotations and ultimate curvatures.

Section	L(mm)	θ_y (10^{-3}rad)	θ_C (10^{-3}rad)	χ_C(10^{-3}m^{-1})
IPE750	7000	4.87	48.7	63.2
	6000	4.18	41.8	54.3
	5000	3.48	34.8	45.2
IPE600	7000	6.22	62.2	103.7
	6000	5.34	53.4	89.0
	5000	4.45	44.5	74.2
IPE550	7000	6.78	67.8	123.3
	6000	5.88	58.8	106.9
	5000	4.84	48.4	88.0
HEM600	4000	3.1	31	50.0
HEM700	4000	2.56	25.6	35.8

Table 6. Ultimate capacities.

Load pattern:		Modal		Uniform	
green roof:		no	yes	no	yes
d_C	[cm]	33.8	33.7	27.4	29.5
F_C	[MN]	6.88	6.63	8.26	8.14

5 Results - Seismic Performance

5.1 Capacity Curves and Ultimate Capacity

For information purposes only, Table 6 presents the ultimate capacities of the portal frame under analysis, defined in this study as the ultimate displacement d_C and the ultimate base shear F_C for which, at some section, the ultimate curvature χ_C (point C of Fig. 6b) is reached. Figure 7 presents the sections where the ultimate curvatures are first reached. For the uniform load pattern, the ultimate capacity is first reached at the base of columns C2 to C5, see Fig. 7, independently of the existence of the green roof.

For the modal pattern, the ultimate capacity is first reached at the middle span of the second-floor central beam, Fig. 7, with and without green roof.

5.2 Target Displacements and Seismic Performance

Table 7 presents the target displacement and force determined by the pushover procedure (N2 Method), corresponding to the 1st and 2nd iterations of the method. As expected, the 2nd iteration displacements are smaller. Note that in EN 1998–1 the improvement of the results of the first iteration by means of the iterative procedure is optional. To take into account the torsional effects, the factor $\delta = 1{,}6$ (section 4.3.3.2.4 of EN 1998-1) was applied to the previous results giving the results gathered in Table 7. Table 8 and Fig. 8 also present the displacement d_{SD} corresponding to the SD limit state being first reached in one of the critical sections. Figure 8 also presents the values of the safety ratio

$$\alpha = d_t / d_{SD} \tag{2}$$

Values of this parameter larger than one means that the structure is not safe with respect to the SD limit sate. The results show the following main observations:

i) the severe damage (SD) limit state is verified both without and with the green roof and for the two load patterns.
ii) The introduction of the green roof does not change the seismic performance of the building, because it causes rather small variations of the ratio α.

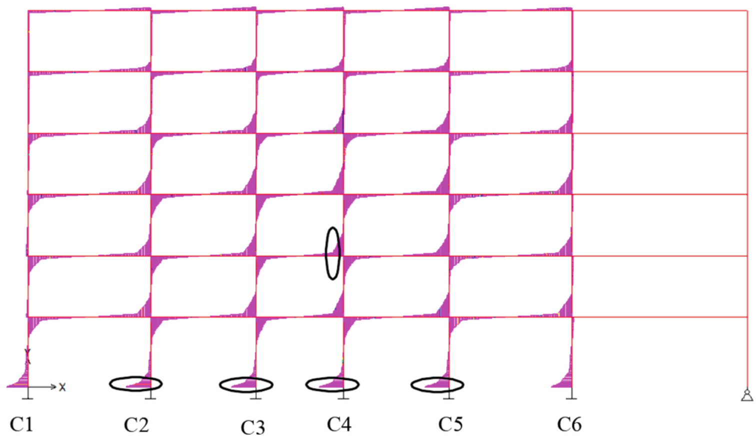

Fig. 7. Critical sections where the ultimate capacity (point C in Fig. 6) is first reached (curvature diagram – EvalS output).

Table 7. Target displacements and target forces.

iteration	torsion	pattern:		modal		uniform	
		green roof:		no	yes	no	yes
1st	no	$d_{t,\text{no torsion}}{}^{(1)}$	[cm]	13.8	14.6	9.6	10.2
		$F_{t,\text{no torsion}}{}^{(1)}$	[MN]	5.21	5.15	5.21	5.34
2nd	no	$d_{t,\text{no torsion}}{}^{(2)}$	[cm]	12.3	12.8	9.5	10.0
		$F_{t,\text{no torsion}}{}^{(2)}$	[MN]	4.78	4.76	5.21	5.20
2nd	yes	d_t	[cm]	19.6	20.4	15.1	15.9
		F_t	[MN]	6.08	5.93	7.11	7.07

Table 8. Global safety with respect to the SD limit state.

load:		Modal			Uniform		
green roof:		no	yes	Var	no	yes	Var
d_{SD}	[cm]	28.9	31.6		20.7	21.6	
d_u	[cm]	33.8	33.7		27.4	29.5	
d_t	[cm]	19.6	20.4		15.1	15.9	
$\alpha = d_t / d_{SD}$		0.68	0.65	4,8%	0.73	0.74	0,5%

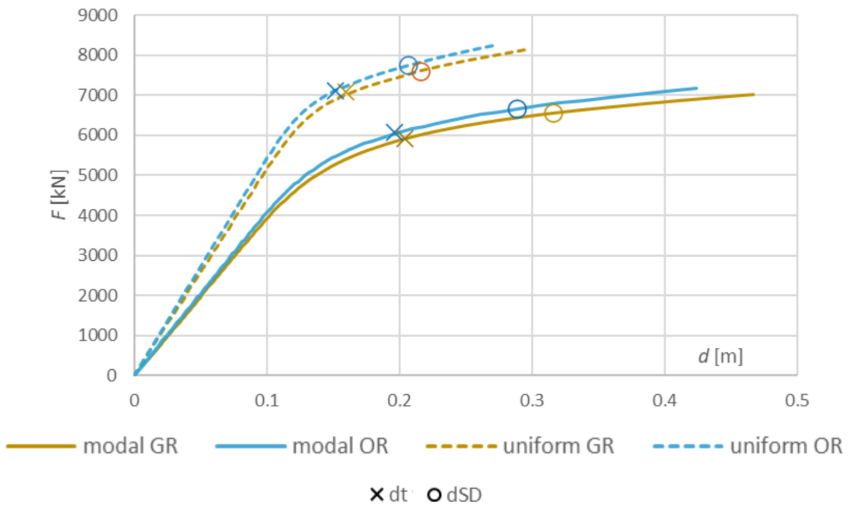

Fig. 8. Capacity Curves and target points (GR and OR mean w/ and w/o green roof; d_t corresponds to the target point and d_{SD} is a measure of the SD capacity).

6 Conclusions

In this study, the influence of adding an extensive green roof to a six storey office building, with steel structure, under a specific seismic demand, was assessed, by a nonlinear static pushover procedure (N2 Method). It was shown that, for the investigated case (concerning only the seismic safety checks), the introduction of the extensive green roof does not affect the safety with respect to the Severe Damage limit state, and the variation of the overall performance is less than 5%.

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Infrashelter Platform: Analysis of Materials Applied in Furniture Solutions for Planned Temporary Camps (PTC) in Disaster Scenarios

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Abstract. This work focuses on the selection of materials for the design of furniture in Planned temporary campuses (PTC) for disaster scenarios. It aims to assess the suitability of furniture for emergency structures based on a selection model called ESA-MOD, considering the main component materials of this equipment. A bibliographic review is carried out, a systematic search for literature encompassing the emergency campus and the selection of materials, including furniture-type objects for the PTC, previously cataloged by a preliminary project called "the Infrashelter Project". An evaluation tool is used for a case study, a comparison between two furniture solutions under a sustainability approach, to assist in making informed decisions, enabling to propose sustainable furniture for PTC facilities that meets the requisite criteria, allowing homeless/refugee people who will live there, to approve spaces and define adequate accommodation.

Keywords: Planned temporary campus (PTC) · Furniture materials · Sustainability · Decision-making models

1 Introduction

The contemporary humanitarian crisis resulting from population exposure to hazardous emergency situations, such as armed conflict and economic or political collapse, often triggers socio-environmental disasters. Conversely, they can also be due to natural extreme events, such as tsunamis, droughts, floods, earthquakes, and hurricanes, causing extreme vulnerability to the health, safety, and well-being of affected populations. These disasters occur at different scales so that they can be classified into four intensity levels: small, medium, large, and very large (Castro 2009). As a result of climate change, natural disasters have been worsening. Additionally, the increasing human intervention in the environment (intensive processes of urbanization, degradation, and neglect in environmentally preserved areas (Cruz 2021; Carbonari 2021) and the severity of political crises

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led to an increase in the number of people in a situation of vulnerability. According to the United Nations High Commissioner for Refugees (UNHCR 2024), at least 96 million people around the world were forcibly displaced in 2022, and most of them became homeless.

Thus, actions are required to help, defend, and preserve the lives of homeless people in vulnerable situations. One of these necessary actions concerns housing, which must be a healthy place that meets basic needs such as sanitation, electricity, food, safety, and cultural respect. These objectives must also ensure humanitarian facilities, a welcoming environment, and medical and psychological support to assist in social and emotional recovery, providing a dignified life for this fragile population (UNHCR 2024; Sphere Association 2018).

Together with physical support for humanitarian crises, it is essential to offer humanitarian goods, such as furniture, equipment, and utensils, to compose the spaces and meet the needs of sheltered people, as stressed by Savonen et al. (2018), Ye and Yan (2020), Humanitarian Coalition (2024) and Nielsen (2020). This research work focuses on movable objects, specifically furniture. There are minimum requisite conditions for humanitarian logistics that must be met, especially concerning the selection of the material components composing them.

The furniture project integrates the activities of the so-called Humanitarian Design by Nilsen (2020); it should consider the cultural appropriation and the needs of the homeless, as well as the support services necessary for making the object. Moreover, one of the central issues challenging humanitarian logistics is the goods that must be available where and when needed, in the appropriate quantity required, from a demand challenging to predict.

In addition, it is necessary to consider the sustainability issue from an environmental risk assessment view so that the needs are met with minimal impact, not compromising the recovery, aggravating existing problems, or causing new ones. Issues such as transportation, land, use of natural resources, production, acquisition, and choice of materials must be considered. These issues are indispensable for the planning and design process of the campus mobile shelters (SEDEC–RJ 2006) and the necessary goods for these places.

This research is part of the implementation work for the Infrashelter Platform Project (VIRTUHAB 2024a) to systematize, catalog, and make available information on PTCs to serve the homeless population. In addition, new types of shelter and furniture for the installations are proposed. More specifically, this article discusses sustainability in the material selection process, focusing on two case studies aiming for more sustainable alternatives that contribute to implementing new PTCs. This issue is part of another project developed by the Virtuhab Research Group, the Materioteca (VIRTUHAB 2024b), which aims to provide designers with information on the material life cycle.

In this work, based on a selection model (ESA-MOD), we investigate the adequacy of the use of furniture in PTCs, under the component materials of these equipments.

2 Methodological Procedures

This research seeks specific solutions for a given context, such as furniture design for PTCs. According to Fleury and Werlang (2016), applied research is a set of activities in which previously acquired knowledge is used to collect, select, and process facts and data, obtain and confirm results, and generate impact. In this work, the following steps were carried out:

i. Exploratory Review – an extensive search for conceptual references in humanitarian assistance and crises, PTC, furniture for emergencies, materials, and material selection tools in design;
ii. Systematic Literature Review – a wide search was conducted on recent articles and publications that could answer the question, "Which choice of materials can be used in furniture for temporary structures implemented in PTCs for disaster scenarios?". This search comprised different words, such as furniture, campus, refugee, material, and design. Data was selected, including publications from 2010 to the present, corresponding to the available data in the Infrashelter Platform. Five articles were considered the most representative in relation to the search words (Table 1);
iii. Two cases of furniture were identified among those already cataloged in the CAPES Infrashelter Project, using the material selection process based on the ESA-MOD Model. This model, proposed by Ferroli and Librelotto (2012), performs a qualitative evaluation using some criteria for the selection of the material, given the economic, social, and environmental dimensions of sustainability;
iv. Evaluation of the suitability/compliance of the material selection process for the furniture.

This ESA-MOD model, explained in the theoretical framework, will enable the proposal of sustainable and adequate furniture to meet the required criteria at a later stage of this work.

3 Theoretical References

The theoretical framework addresses some concepts and classifies them in meaningful terms, namely PTC, furniture, and tools for materials selection.

The humanitarian support structures have different classifications, varying according to the objective. Quarantelli (1991) considers four typological differences between shelters and dwellings for emergencies. These dwellings usually have existing structures, such as churches and schools. Temporary shelters need more infrastructure and services for several months compared to the previous ones. Aburamadan (2022) highlights that shelters do not need to restore the daily routine and activities of the homeless but rather support them in returning to their homes. In the Brazilian reality, emergency shelters quite often become permanent solutions.

Thus, based on the concept of shelter type, this research work focuses on the structures intended for the planned campus (PTCs): reception and sorting, administrative space, storage, storage of goods, space for psychosocial and healthcare, educational and recreation spaces, community areas, kitchens, stock and food distribution, laundry,

Table 1. Final result of the CAPES periodic portal systematic review.

Reference	Objective and content
Savonen et al. (2018)	This paper develops a new 3-D printer for humanitarian crisis sites, designed for fast and reliable manufacturing. This printer allowed producing useful and necessary elements for hospital environments
Moran et al. (2021)	This paper proposes the Integrated Transdisciplinary Tools (ITT) for temporary refugee housing to minimize the complex limitations of the design process
Dalal et al. (2018)	This paper describes the planning of various emergency shelters. It performs a comparative and critical analysis to prove the hypothesis - controlling bias on refugees, i.e., applying some control over their destination
Mohareb and Maassarani (2018)	This article presents a DB (Design-Build) experience conducted with students from an Architecture program in Lebanon. Its object was to design a refugee shelter unit built as a full-scale model. In the design process and selection of materials, some restrictions were introduced, such as shape, size, materials, function, cost, and usability. In addition, the unit could not be fixed in place (mobile/removable), taking advantage of light materials in a limited area, requiring minimum construction effort, and allowing self-construction by people without training, using local materials. Key indicators were established for the shelter project
Aburamadan (2022)	This paper addresses the inadequacy of materials used in refugee shelter design. The research evaluates the temporality of shelters and appropriation space (construction and humanitarian goods) used by refugees in Jordanian camps

emergency/temporary shelters and other possible structures (Carbonari 2021). Humanitarian goods are assumed to be an objective, focusing on furnishings and allowing these spaces to comply with their intended roles.

Ferroli et al. (2019) proposed a classification for furniture, mainly considering usage aspects. The categories initially established were as follows: residential furniture, internal condominium furniture, external condominium furniture, and urban furniture designed for external use, with many users, in environments with free public access (squares, walkways, bridges, parking lots, etc.). However, this classification does not include furniture for emergency architecture, which quite often has specific characteristics. They need to be compact due to the space restrictions of the camps to serve the homeless/refugees. They should also be lightweight to facilitate transport and assembly, preferably by space users (Mohareb and Maassarani 2018). This last characteristic requires that the assembly is easy to understand and materials meet circularity, availability, and recyclability requirements while also considering site sustainability.

Although the furniture used on campus should have a specific project, due to its specificities, it is not uncommon to use ordinary objects in the daily life of traditional spaces, such as old sofas, mattresses, plastic tables, and chairs, often reused from other temporary structures, as long as they are versatile enough to assume their new role on campus.

It is important to note that products designed for the market differ from those designed for social purposes, such as the necessary equipment for planned campus sites. Monteiro (2017) compares social and market design, in which the objective of social design is the satisfaction of human needs, whereas market design focuses on sales and promotion.

Humanitarian aid seeks to meet the needs of individuals in emergencies, and it can be subdivided into supply categories: food, shelter, non-food items, water, sanitation, and sanitation infrastructure. According to the Humanitarian Coalition (2024), non-food items are goods and supplies necessary to maintain sanitation, privacy, and dignity to meet hygiene needs, food preparation, and the thermal comfort of refugees. These items may include clothing, blankets, beds, household items, water containers, and hygiene products.

The Infrashelter Project focused on the occurrence of planned camps in Brazil and the world. So far, ten campuses have been cataloged, allowing us to identify the humanitarian goods, focusing on the furniture used, considering its composition, efficiency, and level of sustainability.

Several tools are aiming to select materials for furniture or even considering materials as decision factors in design, which are as follows: i) *ASUS – Avaliação de Sustentabilidade* [Sustainability Assessment]; ii) *ISMAS – Instrumento para seleção de materiais mais sustentáveis* [a tool for selecting more sustainable materials]; iii) LCA- Life Cycle Assessment, one of the most comprehensive and efficient tools for product evaluation; iv) *FEM – Ferramenta de escolha dos materiais* [Tools for material selection]; v) *FEAP-SUS – Avaliação do ciclo de vida* [Tool for Projects with an emphasis on sustainability], derived from FEM, and vi) ESA-MOD - ESA Model for a thorough sustainability assessment of products, involving economic, social, and environmental aspects, used for the evaluation of materials in this research work for its easy application. It is an adaptation of the ESA model (Bissoli-Dalvi 2014; Ferroli and Librelotto 2012; Librelotto 2009; Librelotto et al. 2012).

Criteria were established and standardized in two groups: product/object fabrication material and manufacturing process. When the assessment is carried out, grades are attributed through comparisons between different material options that can be applied to the object based on quantitative and qualitative information (Ferroli and Librelotto 2012).

To conduct the evaluation, the preferred material is evaluated, always comparatively to others that are available, and then will receive a grade by qualitative and comparative analysis. The general evaluation is done through a simple arithmetic average on economic, social, and environmental issues. The averages of each axis are positioned in the ESA quadrants according to the terminology and evaluation of established ranges.

Based on the ten PTC catalogs available on the Infrashelter Platform (VIRTUHAB 2024b), it was possible to survey the constituent materials of the furniture for different PTC locations. Due to the difficulty in obtaining specific information, the assessment was based, in general, on the materials used in the furniture. The plastic is present in 44.16% of the objects.

4 Application of the ESA-MOD Tool

Considering the data collection regarding the materials used in the furniture in the planned camps, it was noticed that plastic is one of the leading materials used. It was also noted that a standard furniture element in most of the assessed shelters is the plastic table. Therefore, we opted for this furniture element to conduct the sustainability assessment using the ESA-MOD tool. This model was selected based on Ferroli and Librelotto (2012), who previously applied it in a prototype with satisfactory results, allowing a global and simplified sustainability assessment. To allow an adequate evaluation, the plastic table will be compared with a corrugated cardboard table, and furniture will be proposed based on the work of Araujo (2021) for emergency architecture.

This work used a widely used plastic table purchased from a manufacturer located in Santa Catarina, Brazil (Rei do Plastico 2024), composed of polypropylene (PP), produced through a thermoplastic industrial process, with the following characteristics: low cost, easy coloration, high chemical resistance, flexural or fatigue fractures, impact, good thermal stability, low electrical conductivity, atoxic, lightness and easy to mold. This last characteristic enables the material to be recycled; it can be melted and transformed into different products (Gorni 2003).

The corrugated cardboard has cellulose, a widely available raw material, using either wood from planted forests, by either recycling paper chips discarded in the process, or the discarded material itself (Araujo 2021). This material is formed by one or more corrugated elements, called core, fixed using adhesives, in one or more flat elements, called cover. According to its configuration, they are classified as single face, single wall, double wall, triple wall, and multiple walls. In addition, they are classified according to the characteristics of the wavelets, such as number, width, and thickness. Although corrugated cardboard is more used in packaging for transport, its versatility, lightness, and resistance allow it to present different configurations and formats. In 1968, for instance, this material was first used in furniture by the designer Raacke, who designed the chair known as Easy Chair Otto.

Araujo (2021) proposed a table consisting of type B wave corrugated cardboard, approximately 4mm thick, and double or single wall if possible. Being 1 m × 1.20 m, following a proposal for folding and fittings. Thus, there is a facility for assembly carried out by the residents. Based on the abovementioned information, it was possible to apply the ESA-MOD to these furnishings and compare them:

<u>Corrugated Cardboard</u>

Economic Factors – R$ 89.90; Weight (Approx.) of 8 kg. Bending, cutting, and fittings. Commercial measurements of the plates. Cutting, bending, and assembly (can be manual). Electricity spent on manufacture of plates. The manufacturing time of the number of plates required, cutting. Assembly time of a table – 2 min – Cartone (2024). Score: E1 (7); E2 (7); E3 (10); E4 (9); E5 (5); E6 (8); Average (7.66).

Social Factors – There are no suppliers in the region to prepare or assemble ready products. The sheets of paper can be obtained in at least nine locations (Araujo 2021). The materials are locally available. There are many suppliers for cardboard sheets. Existence in the area: There are alternative materials in the area, in the impossibility of using the material of first choice. There is also an income generation for the region. There are some companies capable of manufacturing the raw material used in the model (in the region); there are no trained labor workers in the region who specialize in producing the raw material used in the processing. Score: S1(7); S2 (8); S3 (8); S4 (9); S5 (8); S6 (6); Average (7.5).

Environmental Factors – The possibility of recycling the used material is 100%; the possibility of reusing the material used is 86%; natural and/or recycled material; energy expenditure spent on the manufacture of plates is low (1%), and 63.40% can be sold for recycling, reuse, considering each factor for the analysis. Score: A1(10); A2 (8); A3 (10); A4 (8); A5 (10); A6 (7); Average (8.83).

Polypropylene Plastic

Economic Factors – R$ 99,00; Approx. 4.5 kg Injection Process, with or without amendment; Commercialization in pellets; Injection Machine; Electricity spent on plate manufacturing; Injection time of a table; Score: E1 (8); E2 (5); E3 (7); E4 (5); E5 (8); E6 (7); Average (6.66).

Social Factors – There are several regional suppliers, manufacturing, and material marketing stores. The pellets could be obtained in several locations (Araujo 2021). The materials are locally available. Existence, in the area, of alternative materials in the impossibility of using the material of first choice; Income generation for the region, there are some regional companies capable of manufacturing the raw material used in the model, but there are no trained labor workers in the region, specialized in the production of the raw material used in processing. Score: S1(10); S2 (8); S3 (8); S4 (8); S5 (8.5); S6 (6); Average (8.08).

Environmental Factors – The possibility of recycling the used material is 100%; The possibility of reusing the material used is 100%; natural and/or recycled material; Energy expenditure spent on the manufacture of plates is medium (20%) and 100% can be sold for recycling, reuse, considering each factor for the analysis. Score: A1(10); A2 (19); A3 (5); A4 (5); A5 (7); A6 (10); Average (7.83).

Observations:

a. A table can be made with several materials: concrete, steel, aluminum, iron, glass, decorative stones, and wood, among others. In this analysis, paper and plastic are relatively low-cost compared to others. Cardboard, however, is the cheapest, so it earned a higher score than plastic.
b. Plastic and paper are lightweight materials compared to other alternatives. The weight reported is relative to the approximate quantity for the two projects.
c. The loss of the plastic injector is less than the loss of the corrugated cardboard cut.
d. The cardboard table involves many activities, some of which are manual, while virtually the entire plastic manufacturing process is carried out by a machine. Even using different degrees of automation, manual labor is minimal.
e. The electricity expenditure is much higher on the plastic table (the more automated the process, the greater this expenditure will be).

f. The context of the application was considered, and, in this case, the cardboard table (although the manufacturer's website informs a time of only 2 min) has a comparative loss with the plastic table, which is already ready for use.

5 Final Considerations

This paper focuses on the selection of materials for designing PTC furniture in disaster scenarios. There are only a few research works on this emerging issue; the purpose of this work was to present a comparative evaluation, using the ESA-MOD material selection tool, between a plastic and a corrugated cardboard table.

Initially, a systematic review was carried out, which resulted in only five core articles. Subsequently, the concepts of the types of shelters and dwellings for emergency scenarios were explained, as well as the classification of furniture for residential, urban, and emergency architecture. The relevance of the material used in the design of products was highlighted, and some critical aspects of humanitarian design, such as sustainability issues, were considered.

The ESA-MOD tool, an adaptation of the ESA model, was used to evaluate the economic, social, and environmental sustainability aspects of the selected case study presented in this paper. The furniture and its primary component materials were identified for use in the temporary campus, designed for disaster scenarios, and cataloged in the Infrashelter Platform. As a result, the plastic table with the largest scope was obtained. This plastic table was chosen for the comparative analysis, together with the corrugated cardboard table proposed by Araujo (2021).

The results show that the plastic table has an average of 8.08 on the social factor, 6.66 on the economic factor, and 7.83 on the environmental factor, resulting in an overall average of 7.52. The corrugated table has an average of 7.5 in the social factor, 7.66 in the economic factor, and 8.83 in the environmental factor, resulting in an overall average of 7.99. Thus, it is noted that the cardboard table can be considered more sustainable, according to the ESA-MOD tool, than the plastic table, which is more used in PTC, considering the perspective of the person responsible for this assessment. However, it is noteworthy that this partial conclusion is relative to the context and cannot be understood definitively. The ESA-MOD tool can assist in structuring some relevant factors for the designer's analysis regarding sustainability, and the scores are based on qualitative evaluations. It is important to contemplate the limitations of the research method. This tool only tells the designer that, in a particular context of PTCs and for a specific type of furniture, data can be structured on the furniture in a way that can facilitate a general understanding, explain the criteria, and assist in taking a decision, suggest an option with a better result. These results support the next stage of this ongoing work: propose sustainable furniture for the PTC facilities that meet the requisite criteria, allowing homeless people who will live there to approve spaces and define adequate accommodation.

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Recycling Composite Food Packaging: Recovering and Valorization of Individual Components

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Abstract. Paper composite packaging, increasingly used in various sectors including food, offers benefits like enhanced product preservation. However, its recycling poses challenges due to the difficulty in separating its components, leading to waste accumulation in landfills or incineration. This work aims to develop a sustainable recycling strategy to address this environmental issue. The methodology was designed to investigate and assess the materials present in composite packaging, their compatibility with various solvents, and the feasibility of recovering packaging components such as paper, synthetic polymers, metals, and others. Additionally, the study aimed to recover solvents used in the process and determine the calorific value of the recycled samples. Using Hansen Solubility Parameters, we identified the most effective solvents for dissolving the composite food packages under analysis. Following solubilization, two samples (SL1' and SH1') were selected for further investigation, both dissolved using *p*-Cymene. These samples underwent FTIR-ATR and NMR analysis, that enabled the identification of specific polymers, including PE (Polyethylene), LDPE (Low-density polyethylene), HDPE (High-density polyethylene), PP (Polypropylene), and PC (Polycarbonate), present on those composite packaging. Furthermore, both samples were incinerated, and their calorific values were measured, ranging from 18.19 to 18.76 $MJkg^{-1}$, demonstrating that they have potential for being valorized via energy recovery.

Keywords: Recycling · Paper composite packaging · Polymers · FTIR-ATR · NMR · Valorization

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1 Introduction

Paper stands out as an exceptional and versatile material, extensively employed in daily life across numerous applications like printing, household items, and beyond. Its myriad of advantages includes biodegradability, lightweight nature, robustness, and recyclability. Furthermore, its affordability renders it a prime choice for many industries [1]. Presently, paper fulfills a plethora of roles, prominently featuring in packaging, the arts sector, hygiene products, and technology-related items, underscoring its enduring significance in contemporary society [2]. Recycling is essential for environmental sustainability, especially for paper-based products. Understanding the recycling processes is crucial for reducing the environmental impact of paper production and disposal. While regular paper recycling is quite straightforward, the same cannot be said regarding the recycling of paper based composite food packaging since it is more complex due to the polymeric coatings used, leading to an inefficient form of recycling [3]. The EU Packaging and Packaging Waste Regulation (PPWR) and other entities have highlighted the significant challenges posed by the widespread use of chemicals in paper-based packaging. Countries like Brazil, Finland, Sweden, and others are grappling with the high demand for fresh pulp to produce paper, exacerbating environmental concerns. Moreover, food packages containing paper hinder the recycling process, with fully plastic packages being deemed 74% more recyclable than their paper counterparts. 42% of chemicals that constitute paper-based food packages are considered as substances of concern that present health risks due to their persistence and potential to cause cancer or disrupt human hormonal systems and more importantly, these toxins can migrate from packaging, contaminating food and posing serious health hazards to consumers [4]. Composite paper food packaging blends different kinds of polymers to create a container that offers better protection and durability. These packages typically consist of multiple layers, ranging from 3 to 12 for general use and 3 to 7 for food packaging [5]. These main layers include the outer layer for printability and mechanical stability, tie layers to improve interlayer adhesion and strengthen layer bonding, functional layers that act as barriers to oxygen, moisture and light, and the inner layer that must remain inert and provide effective sealing at lower temperatures [5]. In this paper we sought out to create one or more chemical systems to be able to separate the chemical components found in these types of packages in order to facilitate paper recycling and to also understand if these materials may be used for thermochemical processes. To select the most suitable solvents for separating the different types of polymers from the composite food packages, we used the Hansen Solubility Parameter. The Hansen Solubility Parameter (HSP) assesses the compatibility of a solvent with a material based on three key components: non-polarization/dispersion forces $_{(ED)}$, permanent dipole-permanent dipole forces $_{(EP)}$ and hydrogen bonding forces $_{(EH)}$. The combination of these components gives us the HSP, which reflects the solubility of a material. Comparing the HSP values between a solvent and a material helps to determine their affinity. Similar values indicate a high affinity, suggesting that the solvent is likely to be effective in dissolving the polymeric material [6]. After the successful solubilization, the two methods chosen to analyze the mixture achieved were FTIR-ATR (Fourier-Transform Infrared Spectroscopy-Attenuated Total Reflection) and NMR (Nuclear Magnetic Resonance). FTIR spectroscopic imaging, particularly in the attenuated total reflection (ATR) mode, has become a valuable tool in scientific research due to its label-free, non-destructive and chemically specific nature. The ATR mode offers precise control over the depth of penetration and path length of infrared light into the sample, making it particularly attractive for various applications. This technique uses sharp characteristic bands in the infrared spectrum to identify specific chemical components within the sample [7, 8]. NMR spectroscopy is a noticeable and versatile analytical tool used to study the structure and interactions of molecules. It provides detailed information regarding chemical environment, connectivity, and interactions of atoms at the atomic and molecular level. This non-destructive technique is widely used in several fields, including structural elucidation, drug discovery, medical imaging, materials characterization, reaction monitoring, among others. Applications in materials science, particularly in structural elucidation of polymers, has been widely described in literature [9, 10].

2 Materials and Methods

Two distinct sets of samples, comprising a PCP (paper composite pack) and a TPP (TetraPak package), were employed in the study. Each sample set underwent chemical impregnation using two different systems, each composed of a blend of solvents. These solvent combinations were specifically designed to ensure optimal conditions for dissolving the polymers commonly present in such packaging materials while enabling the isolation of the paper matrix for subsequent recycling purposes. To prepare the samples, the packaging materials were cut into 1 cm x 1 cm squares, with each sample weighing 4.0 g to ensure an uniform impregnation by the solvent. The systems were designated as SH for paper composite packaging and SL for the TetraPak packaging. The experiment was conducted using round-bottomed flasks in which the samples and solvent were combined and heated using a heating mantle. To maximize solubility, the combinations of packaging pieces and solvent were heated until they reached their boiling point, maintaining the system at reflux using a suitable condenser. This reflux condition was sustained for the required duration in order to observe the dissolution of the various polymers. This method was chosen to preserve the solvents for subsequent polymer analysis after dissolving them. Two systems, designated as S1 and S2, were employed, each resulting in a series of liquid fractions before and after washing the chemically impregnated packaging pieces, labeled as SH1/SL1 and SH2/SL2, respectively. Each system, S1 and S2, involved the use of four solvents, requiring four stages of processing. In each stage, the solvents were heated to their boiling point for two hours, then cooled to room temperature, and finally dried in an oven at 80 °C for up to 20 h. Afterwards, the equipment used to analyze the samples were FTIR-ATR (PerkinElmer FT-IR Spectrum Two) and NMR. ^{1}H NMR spectra were conducted on a Bruker Avance III instrument at a frequency of 400 MHz. Chemical shifts (δ) are given in parts per million (ppm) with respect to the Deuterated chloroform solvent ($CDCl_3$, ^{1}H: $\delta = 7.26$ ppm). For the calculation of Higher Heating Value (HHV) a theoretical assessment was made using Eq. 1 [11].

$$HHV\left(MJ.kg^{-1}\right) = 0.3491(\%C) + 1.1783(\%H) + 0.1005(\%S) - 0.1034(\%O) - 0.0151(\%N) - 0.0211(Ash) \quad (1)$$

3 Results

3.1 FTIR-ATR Analysis of the Recycling Process: Case of SL1´and SH1´ Solubilized Samples

Both samples and the extracts were analyzed via FTIR-ATR. The wavelength established in this analysis was between 4500 cm^{-1} and 400 cm^{-1} while performing a number of 20 total scans per sample. For this article, samples designated as SL1´ and SH1´ were chosen for analysis SH1´corresponds to the sample extracted from the CP package by *p*-Cymene and the SL1‘corresponds to the sample extracted from the TPP package by *p*-Cymene. Both samples are from the number 1 system of solvents developed. Firstly, both samples were analyzed via FTIR-ATR while solubilized by the solvent *p*-Cymene. Figure 1 shows the spectra of both samples and also the spectrum of the *p*-Cymene used in this work.

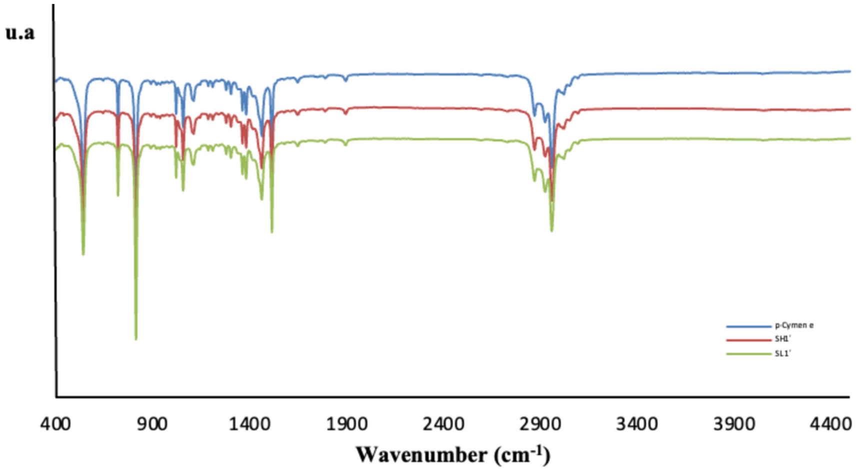

Fig. 1. Spectra of *p*-Cymene (blue line), SH1´solubilized (red line) and SL1´solubilized (green line).

All three spectra (Fig. 1) are very similar to one another. We can only notice a few differences regarding the intensity of the signals, and even then, they are almost all equal to each other. This preliminary analysis can mislead into believing that the extraction method applied did not work (i.e. from samples SL and SH, no material of any kind was extracted.). To prove this initial thought wrong, the mixture of both SL1´and SH1´samples was dried to ensure a new analysis of the solid samples without the interference of the solvent *p*-Cymene in the FTIR-ATR analysis.

3.2 FTIR-ATR Analysis of the Recycling Process: Case of SH1´ and SL1´ Solid Samples

The drying process consisted in providing constant heat to the sample. The samples ended up being dried in an oven at 75ºC for 4 days. This ensured that the solvent was consistently being evaporated while the sample remained intact. After this time, a solid deposit was formed at the bottom of both goblets. This solid deposit was then analyzed via FTIR-ATR which resulted in two spectra (Fig. 2a, b) with significant differences from the ones presented in Fig. 1.

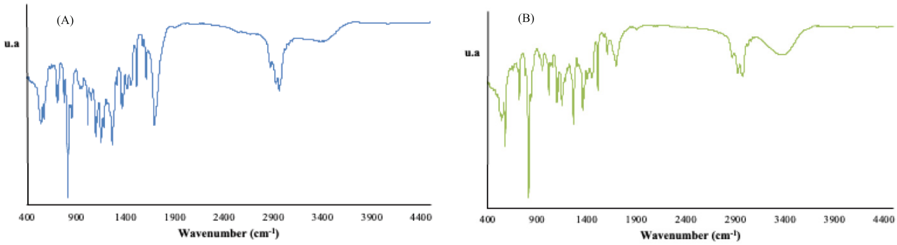

Fig. 2. a) FTIR-ATR spectra of the solid sample SH1´; b) FTIR-ATR spectra of the solid sample SL1´.

3.3 Validation of Recycling Process by NMR Analysis: Case of SH1´and SL1´ Solid Samples

NMR spectra identifies different chemical environments or types of nuclei in the sample, for instance, proton (^{1}H) NMR focuses on the behavior of hydrogen nuclei (protons) in the molecule. In this work we concentrated our attention on the ^{1}H NMR analysis of two samples (SL1' and SH1'), and all the solvents evaporated to dryness. The remaining residues were dissolved in $CDCl_3$ and ^{1}H NMR spectra was obtained for both samples (Fig. 3a and b). Several peaks can be seen in both samples, indicating possible known polymers. According to literature, we postulate that PE, LDPE and HDPE could be present in the residue of both samples [12, 13]. Peaks between 1.33 and 1.83 ppm were associated with the protons of methylene group (-CH_2-), such as the multiple peaks at 4.71–5.40 ppm observable in sample SH1' (Fig. 3b), assigned to protons of the vinyl end group and possibly other kinds of double bonds (vinylidene and vinylene). Sample SL1' (Fig. 3a) also shows two characteristic protons of the vinyl group at 4.79 and 5.15 ppm. Peaks between 0.95–1.00 ppm and 1.18–1.21 ppm, in samples SH1' and SL1', respectively, were associated with methyl groups, such as peaks at 2.91–3.06 ppm and 3.10–3.15 ppm were associated to methine groups, possibly from oligo/polymeric propylene (PP) [14]. Peaks at 2.56 ppm (Fig. 3a) and at 2.40–2.41 ppm (Fig. 3b) were associated with protons of methylene groups, related with LDPE and HDPE [13]. Several peaks between 7.08–8.13 ppm appeared in both samples, indicating the presence of benzene rings (aromatic CH protons). According to literature, those peaks could be associated with aromatic PC, one of the most useful engineering plastics [15]. Traces of unsaturated PC could also be found in sample SH1' (Fig. 3b), according to literature data [16]. No traces of PVC or PU were found in both samples, by comparing data with literature [17–19].

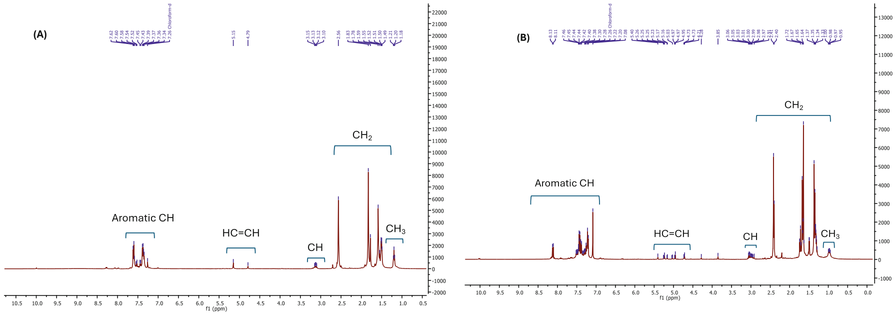

Fig. 3. a) ^{1}H NMR spectra of sample SL1' (A) $CDCl_3$; b) ^{1}H NMR spectra of sample SH1' (B) in $CDCl_3$.

3.4 Energetic Valorization of Recycled Samples

Throughout the various stages of the recycling process there is always the possibility of converting the recycled samples, or the different components of the packaging, into energy. To assess this possibility, the calorific value of specific samples was determined (Table 1), including the starting composite packaging (PCP and TPP).

Table. 1. Results obtained for the theoretical calculation of HHV.

Sample	TPP	PCP	SL1	SH1
Elemental Analysis (wt.%, db)				
Carbon	44.9	34.1	42.1	42.8
Hydrogen	9.1	7.1	9.1	9.5
Nitrogen	0	0.3	1.5	0.4
Oxygen	46.0	58.8	47.3	47.3
Sulphur	0	0	0	0
HHV ($MJ.kg^{-1}$)	19.4	12.6	18.2	18.8
Proximate Analysis (wt. %)				
Moisture	4.8	6.0	2.6	2.7
Volatile matter	69.4	86.1	83.4	59.4
Fixed carbon	25.8	7.9	14.1	37.9
Ash	16.8	6.3	5.8	20.6

4 Discussion

4.1 FTIR-ATR Analysis

Comparatively to the solvent spectrum, some signals characteristic of *p*-Cymene, though present, were notably less prominent, while new high-intensity features emerged. To streamline spectrum interpretation, Table 2 presents the polymers identified in the samples along with the associated probabilities of their presence, providing insight into the composition of the materials under examination.

Table. 2. Types of polymers detected in the SL1´and SH1´samples and probability assessment from FTIR-ATR analysis

Polymer	Sample SL1'	Probability	Sample SH1'	Probability
Polyethylene	PE	High	PE	High
Low-density polyethylene	LDPE	High	LDPE	High
High-density polyethylene	HDPE	High	HDPE	High
Polypropylene	PP	Medium	PP	Medium
Polycarbonate	PC	High	n/d	n/d
Polyurethane	PU	Low	n/d	n/d
Polyvinyl chloride	n/d	n/d	PVC	Low

n/d – Not detected.

4.2 NMR Analysis

After conducting FTIR-ATR analysis, a subsequent NMR analysis was performed to validate the presence of identified polymers in both samples and adjust the associated probabilities. The results are detailed in Table 3, confirming the presence of certain polymers while refining the probability estimates for their occurrence in subsequent samples.

4.3 Energetic Evaluation

The TPP sample, from the original material packaging, has an HHV of 19.4 $MJ.kg^{-1}$, a much higher value than the calculated for the PCP sample. This difference could be explained by the distinct composition of the composite packaging material under analysis. The samples after the chemical recycling process, where solvents are introduced, have a calculated HHV value of around 18 $MJ.kg^{-1}$. Regarding the TPP sample, its post-process pair increases the HHV, so by increasing the HHV it will possibly be a good candidate for thermochemical valorization. The values calculated are in line with those reported in Channiwala and Parikhb [11].

Table. 3. Types of polymers detected in the SL1´and SH1´samples and probability assessment from NMR analysis

Polymer	Sample SL1´	Probability	Sample SH1´	Probability
Polyethylene	PE	Very high	PE	Very high
Low-density polyethylene	LDPE	Very high	LDPE	Very high
High-density polyethylene	HDPE	Very high	HDPE	Very high
Polypropylene	PP	High	PP	High
Polyvinyl chloride	PVC	n/d	PVC	n/d
Polycarbonate	PC	High	PC	Medium
Polyurethane	PU	n/d	PU	n/d

n/d – Not detected.

5 Conclusion

This paper presents a possible strategy for tackling the problem of composite food packaging. This approach is based on a sequential solvent extraction process that allows the separation of the different components of the package, the extraction and recovery of the polymers that make up the package, and the solvent itself. The efficiency of this chemical recycling process was confirmed by FTIR-ATR and NMR analyses, enabling the presence in the solvent of polymers used as constituents or binders of the different layers of composite food packaging to be identified. This approach also facilitates the separation of components such as aluminium foil and the different types of paper used in the packaging. Finally, as a last resource, the possibility of energy recovery of the processed samples after the various recycling steps was evaluated. The results showed HHV values of around 18 MJ.kg^{-1}, indicating that this possibility could also be considered as a last option in the case of these samples of PCP (paper composite packaging for meat) and TPP (TetraPak packaging for milk).

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Increasing the Sustainable Production of Biofuels – Prospects of Cultivating Oilseed Crops in Soils Contaminated with Heavy Metals

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Abstract. The production of oil crops is a promising alternative for the substitution of fossil fuels to secure the production of energy, and several species can be cultivated for it. Some new oil crops are promising due to their oil yields and quality. In addition to the potential for oil production, some species are capable of toleranting heavy metals from the soil. Thus, the current work aims to explore the potential of *Brassica carinata* and *Crambe abyssinica* in soils contaminated with Zn (450 $mg.kg^{-1}$, dm), Pb (450 $mg.kg^{-1}$, dm), Cd (4 $mg.kg^{-1}$, dm) and Ni (110 $mg.kg^{-1}$, dm). *B. carinata* was more productive (160 g/m^2), exceeding crambe (130 g/m^2). Both crops showed tolerance to the heavy metals experimented (tolerance index higher than 0.75). Nevertheless, the oil content in the seeds was somewhat altered by the level of contamination in the soil. Therefore, biodiesel production costs may increase because oil production per land area is reduced due to the level of contamination. Nevertheless, the production of oil crops in soils polluted with heavy metals represent an opportunity to provide feedstock for the oil-based chemical industry, contributing to decarbonize the economy.

Keywords: Biofuels · contaminated soils · heavy metals · oil crops · phytoremediation

1 Introduction

The contamination of soils, due to anthropogenic activities, causes several impacts to the ecosystems [1]. A contaminated soil is more prone to desertification, the contaminants can reach water resources and crops, which can, ultimately, contribute to causing health problems in humans [1–4]. Different technological options can reduce the level of contamination in soils. Those techniques can be biological, physical and/or chemical. But, most of the classical procedures to remediate contaminated soils, are not ecofriendly

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and may produce waste streams that need treatment. Phytoremediation, the utilization of plants to reduce and attenuate the level of contamination in the soils, is a more ecofriendly technology [2]. Among the plants that can tolerate contamination and that can contribute to the soil remediation, energy crops show promising characteristics. Beside the remediation action, the production of biomass may bring further revenue to farmers, once it can be exploited for biobased products, biofuels or bioenergy [3, 5–12]. In addition, the industrial exploitation of those crops for bioenergy and biofuels, will also contribute to reduce fossil energy consumption, augmenting the portion of renewable energy in the global energy mix, in line with Goal 7 of the Sustainable Development Goals of the United Nations. Consequently, by using a renewable feedstock, greenhouse gas emissions will also reduce, helping to meet the objectives of the European Green Deal, that aims to reach no net emissions of greenhouse gases by 2050 [13, 14]. In addition, using contaminated soils to grow energy crops, lessens the disputes over land, since those soils cannot be used for food and feed [13, 15–17]. There are a good range of industrial cops that can be processed and exploited to produce bioenergy and biofuels. Crops rich in lignin and cellulose present high yields and high calorific value [7, 8, 18, 19]. Crops that produce seeds, rich in lipids, can be exploited to produce biodiesel, but also lubricants, plastics, others [20]. Yet, the contamination can affect crops yields. Moreover, biomass quality can be also influenced by the contamination. Therefore, the economic value and the environmental savings can be lower, when producing those crops in soils that are contaminated [21, 22]. In this context, the objective of this study was to evaluate the growth and quality of the production of *B. carinata* and *C. abyssinica* in soils contaminated with heavy metals.

2 Methodology

In November 2020, the essay was established in pots, with two different oil crops: *Brassica carinata* and *C. abyssinica*. Sowing was done in pots with 12 kg of soil. Fertilization was done after the establishment of the plants: 3 g N/m^2 (urea, 46% N); 3 g N/m^2 nitrolusal ($NH_4NO_3 + CaCO_3$, 27% N); 26 g P_2O_5/m^2 (superphosphate, 18% P_2O_5); 17 g K_2O/m^2 (potassium sulphate, 51% K_2O). Artificial contamination was done in each pot with the subsequent heavy metals: Cd, Ni, Pb, Zn. The amount of each metal added to the soil was built according to the limits given by the Decree Law 276 of 2009 (Portuguese regulation, that identifies the conditions for the application of sewage sludge in agricultural soils) – Cd: 4 mg/kg; Ni: 110 mg/kg; Pb: 450 mg/kg; Zn: 450 mg/kg [23]. A control was additionally tested for each crop (soil without contamination). For each studied heavy metal and for the control, replication was set (3 replicates). Pots were irrigated to prevent water stress. In May 2021, when the growing season ended, harvest was made, and the productivity and the number of siliquae was accounted. Nitrogen determination was performed in the digested samples using the Kjeldahl method [24]. The ash content of the different biomass fractions was determined in a muffle (L3/11/C6, Nabertherm, Lilienthal, Germany), using the ASTM E1755 test [25]. In the test, the biomass is oxidized at 575 ± 25 °C and the ash corresponds to the residual mass left after.

3 Results and Discussion

3.1 Biomass Productivity

The effect of the contaminated soils on the average aboveground biomass productivity of the oil crops studied is presented in Fig. 1.

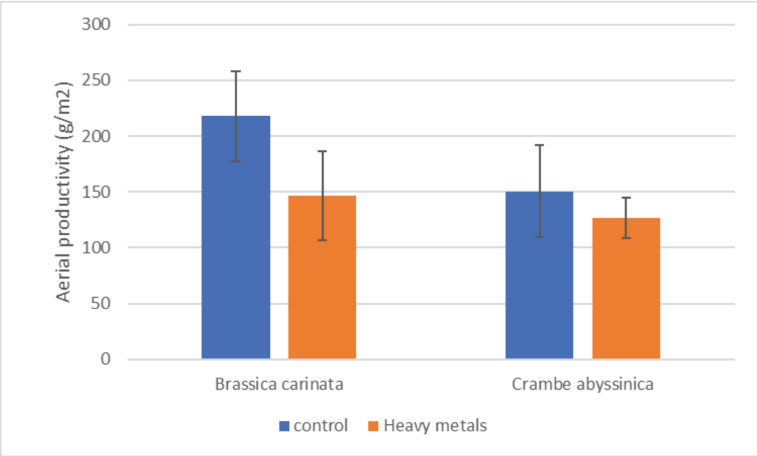

Fig. 1. Oils crops aboveground productivity in heavy metals contaminated soils.

B. carinata was the crop that presented the highest yields, compared to *C. abyssinica.* However, *B. carinata* was more affected by contamination than crambe. The influence of each heavy metal on the average aboveground biomass productivity of both oil crops is presented in Fig. 2. Zinc was the metal that presented the highest effect on the yields, but, for the other metals, no significant differences were perceived.

The impact of the contaminated soils on the average oil crops seed yield is presented in the Fig. 3.

B. carinata presented lower seed yield compared to *C. abyssinica.* And, *B. carinata* seed yield was more affected by contamination than crambe.

The impact of Zn, Pb, Ni and Cd presence in soils on the oil crops seed yield is shown in Fig. 4.

Seed yield was reduced due to heavy metals contamination, and Cd contamination, showed the lowest seed yield. Contamination of the soils with Zn, didn't influenced (negatively) the seeds yield. On the contrary, the contamination of the soils with Zn showed higher seed yield, when comparing with control soils. Both oil crops showed tolerance to the heavy metals in study (tolerance index higher than 0.75).

3.2 Biomass Quality

Seeds were analyzed in terms of the ash, oil, and protein content. The seed's ash content increased due to the contamination of the soil. Zn and Pb contamination induced a higher

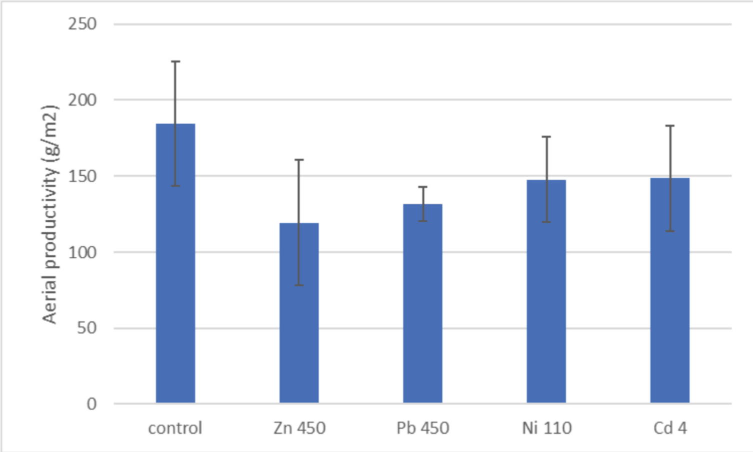

Fig. 2. Influence of the contamination of soils with Zn, Pb, Ni and Cd on the aboveground productivity of the two oil crops.

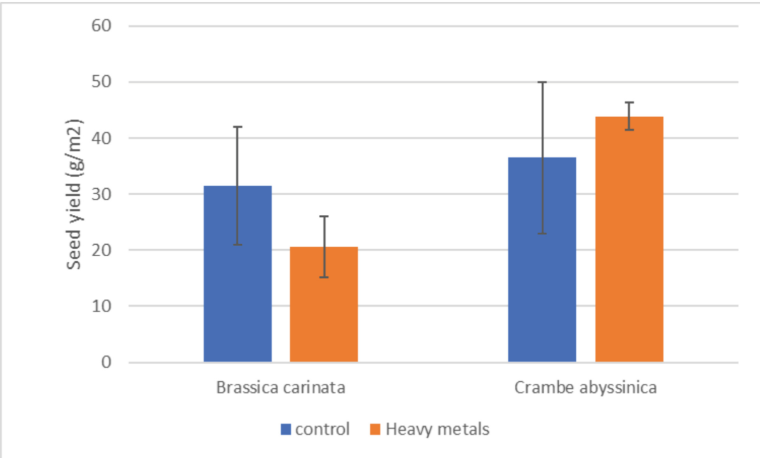

Fig. 3. Oils crops seed yield in heavy metals contaminated soils.

content of seed's ash either of *B. carinata* and crambe. Ni and Cd contamination, also induced a higher ash content in the seeds of *B. carinata.* Yet, crambe seeds ash content was not affected by those two metals.

The protein content of the seeds increased also due to the heavy metals contamination (Fig. 5).

Therefore, the contamination of the soils lowered the seed's oil content (results not showed) and increased protein content. This reduction in oil yield, increases costs of biodiesel production, once oil production per land area was lower due to soil contamination. Nevertheless, the production of oil crops in contaminated soils represent an

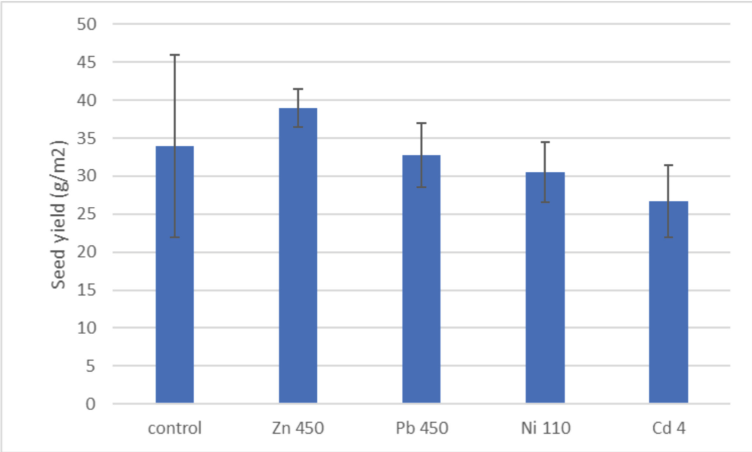

Fig. 4. Impact of Zn, Pb, Ni and Cd, on the oils crops seed yield.

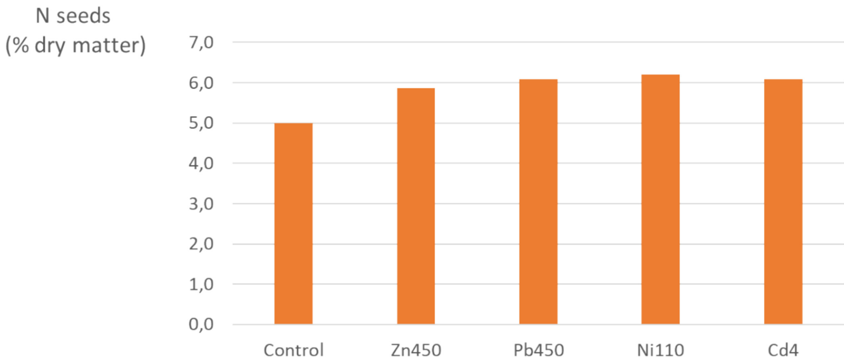

Fig. 5. Influence of soil contamination on oil crops seed nitrogen content.

opportunity to provide feedstock for the chemical-oil industry, contributing to reduce economy's carbon-intensity.

4 Concluding Remarks

Two oil crops were exposed to soils contaminated with Cd, Ni, Pb and Zn. In general Zn affects more the aboveground productivity but the seed yield was not affected. Crambe was the oil crop that showed less effects due to heavy metals contamination.

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Evolution of the Usage of Natural Fibers in Sustainability

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Abstract. During the 70s and 80s of the last century, synthetic fibers replaced natural fibers, due to their better performance and relative low cost. It is only in the last 15–20 years that natural fibers have been gaining ground, largely due to the need to approach the industrial process in a sustainable way, causing a resurgence of interest, which is reflected in the increase in their use. Being sustainability the main concern worldwide, with this increase in fiber consumption, this demonstrates that usage of natural fibers needs to gain more significance and replace the synthetic fibers whenever possible. Natural fibers are an abundant material, light in weight, biodegradable, economical, have good mechanical properties, are from biomass, and are therefore promising in the area of composite reinforcement. Thus, in order to understand the importance of natural fibers, this paper focuses on the growing importance of natural fibers among the scientific community, namely understanding the growth and number of publications since 2000.

Keywords: Natural Fibers · Plant Fibers · Animal Fibers

1 Introduction

The greater global concern with environmental problems and new rules, as well as with the unsustainable consumption of oil, has increasingly contributed to an increase in the use of so-called "environmentally friendly" materials. In the search for new materials, renewable and sustainable resources are sought, promoting a growing interest in the use of natural fibers in composite materials. These materials are considered low-cost, abundant, come from renewable and non-polluting sources (Santiago, 2007). The use of materials that require a smaller amount of energy in their transformation, provide better recycling, both in terms of resources used and in terms of their final decomposition, are of vital importance (Silva, 2006).

Natural fibers are usually included in the scope of this type of materials as opposed to synthetic fibers. In recent years, natural fibers have achieved a promising role as reinforcing material in composites, mainly in bio-based and biodegradable polymeric

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matrices in a more general concept of sustainable development. Natural fibers are an abundant material, light in weight, biodegradable, economical (they are more economical than the synthetic fibers used today to reinforce composite materials such as glass fiber and aramid), have good mechanical properties and are from biomass, and are therefore promising in the area of composite reinforcement. However, there are disadvantages to its use such as low thermal stability, good moisture absorption, low compatibility with hydrophobic polymeric matrices and the quality of the fiber, as this depends on the type of processing it undergoes to obtain it (Eichhorn et al., 2001; Kaith et al., 2011). Hence, new fibers and applications are being developed every year.

Natural fibers are divided into subcategories depending on their origin: plants, animals and minerals (Mohammed et al., 2015). Vegetable fibers are mainly made up of cellulose and animal fibers are made up of proteins. Mineral fibers, on the other hand, have been used less and less because they are heavier and, above all, because they are closely associated with the development of carcinogenic problems in humans (Riedel & Nickel, 2005). The quality and the vast majority of properties of natural fibers depend on factors such as their size, maturity and processing and extraction methods. Furthermore, properties such as density, electrical resistivity, tensile strength and initial modulus are closely related to the internal structure, chemical composition of the fibers and the microfibril angle (angle between the axis and the fiber fibrils). Typically, the smaller this angle, the higher the mechanical properties (Mohanty et al., 2001). In the area of reinforcing polymer composites, the most used are those that come from plants. Plant fibers can be found in the form of hairs (cotton, kapok), hard fibers (sisal, coir), fiber bundles from dicotyledonous plants or vessel bundles from monocotyledonous plants (flax, hemp) and fibers found in trees (Bledzki & Gassan, 1999; Eichhorn et al., 2001; Siqueira et al., 2010).

Fibers are thread-like elements that have a large ratio between their length and thickness, and may be organic or inorganic in nature. They can be divided into two large categories according to the typology of their origin, which can occur naturally or arise from chemical and/or mechanical processes. Fibers are made up of macromolecules, called polymers. A polymer is a structure formed by chains of monomers, that is, units that are repeated throughout a polymer. This association results from the monomers being chemically unstable, which means they tend to group together. This forms the macromolecules that make up the polymer, which already has great chemical stability (Silva, 2022). As a general rule, fibers have high tensile strength, requiring high tensions to achieve significant deformations. Hemp fibers, for example, present deformations at break of less than 5% when subjected to stresses greater than 1 GPa. This behaviour comes from the fact that the macromolecules that make up the fibers align in the axial direction (Pinheiro, 2008).

The following Fig. 1 shows the main types of fibers already used. The fibers are normally classified as synthetic and natural fibers according to their origin.

In the composite materials industry, when natural fibers are mentioned, this term refers only to fibers of vegetable origin originating from the stem, seed, fruit or leaves of some plants. These fibers contribute in a preponderant way to the support of the plant during its life and when they are used in composite materials, natural fibers, being more

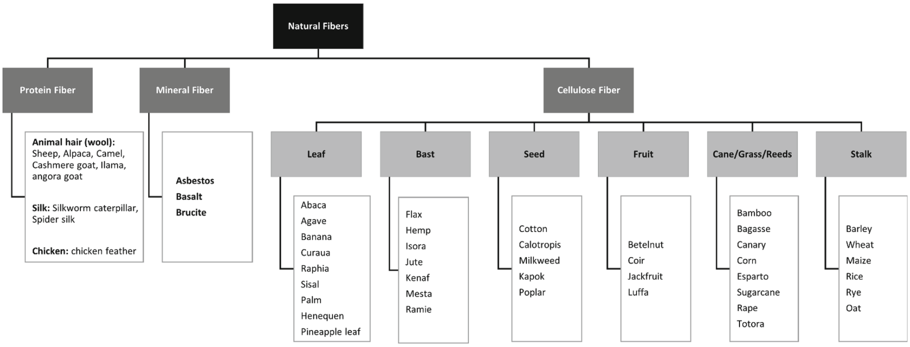

Fig. 1. Classification of Natural Fibers (adapted from Ahmad et al., 2015; Gurunathan et al., 2015; Rodrigues, 2007).

ecological than synthetic ones, are able to provide mechanical properties of great interest (Thomas & Pothan, 2009).

In the field of composite materials, the main characteristics that have led to the replacement of synthetic fibers, mainly glass fibers, are low cost, low weight, good tenacity, attractive thermal, electrical and acoustic insulation properties, good specific mechanical properties (Kaith & Kaur, 2011), and the low abrasion to processing equipment, which natural fibers present (Smith, 2005).

Fibers are normally used as a reinforcing element in composites as they have high tensile strength and stiffness while the matrix keeps them protected and distributes the stress between them and is also mainly responsible for resistance to shear stresses and environmental conditions. The mechanical properties of the fiber normally determine the stiffness and tensile strength of the composite.

In addition to technical and economic factors, natural fibers also have considerable ecological advantages, among which the following stand out (Mohanty et al, 2005; Baillie, 2004):

- The little energy required for its production;
- They are ecologically viable;
- They are widely available around the world;
- They are non-toxic;
- Since they are an organic material, at the end of their life they can be decomposed and used as soil fertilizers;
- At the end of their life, they can also be burned or used as fuel.

In addition to the aforementioned advantages, natural fibers are neutral with regard to carbon dioxide emissions, since the amount of carbon dioxide released when burning is approximately the same as the plant consumed during its lifetime (Smith, 2005).

The increased interest in the use of natural fibers to reinforce polymer matrix composites is mainly due to the possibility of them being obtained from renewable natural resources and allowing them to replace conventional synthetic fibers in some applications. When compared to their counterparts reinforced with synthetic fibers, composites reinforced with natural fibers normally have very satisfactory specific strength and modulus due to the low density that these latter reinforcements present. Although natural fibers have a lower cost than synthetic fibers, initially, the greater variability in their quality and properties depending on the harvest may require treatments capable of causing large fluctuations in their price. The biodegradability of natural fibers is, however, the most important argument in favour of their use as they allow the composites that integrate them to pollute the environment much less and because they can be degraded, recycled or transformed into energy. If natural fibers present adequate costs and performance for a given application, their biodegradability will become an important industrial added value given the environmental and sustainability improvements inherent to them (Leite, 2017; Begum & Islam, 2013).

Composites reinforced with natural fibers also have good thermal and acoustic insulation properties and cause low wear on equipment during processing. The energy expended in the production of these composites is normally a third of that used in glass fiber reinforced composites and their decomposition involves the emission of much fewer toxic compounds than occurs with other composites (Mohanty et al., 2001).

However, there are some limitations in the use of natural fibers as reinforcement for composite materials. One of the main limitations of composites reinforced with natural fibers results from the high water absorption they present, which comes from the hydrophilic nature of natural fibers. Lignin and hemicellulose, structural constituents present in all natural fibers, are responsible for the high water absorption of these fibers and inherently in composites reinforced with them. The water absorbed by the natural fibers ends up damaging the fiber/matrix adhesion, which is normally reflected in a decrease in the mechanical properties of the final composite. The reduction in mechanical properties can also lead to the creation of fractures on the surface of the parts, which accelerate their degradation process.

Another major limitation of these composites is the low temperature at which natural fibers can be processed without degrading and which reduces the range of polymers that can be used as a matrix.

Finally, composites reinforced with natural fibers present a high risk of degradation in exterior applications compared to composites reinforced with synthetic fibers, which limits their durability. This limitation makes it necessary to find solutions that increase the durability of composites reinforced with natural fibers and reduce their degradation so that they can be used as substitutes for those that use synthetic fibers as reinforcement in more demanding applications and environmental conditions, whether/or corrosive (Faruk et al., 2014; Leite, 2017).

The main disadvantages arising from the use of composite materials reinforced by natural fibers can be summarized in the following list (Baillie, 2004):

- They generally have lower mechanical resistance than glass fibers;
- Great dispersion of properties, that is, a non-homogeneous quality of the fibers, dependent on many factors;
- In contact with water, natural fibers present: low resistance to water absorption, high moisture absorption and low dimensional stability;
- Poor adhesion at the fiber-matrix interface which also contributes to a decrease in mechanical properties;

- Low thermal resistance.

1.1 Mineral Fibers

Many natural fibers of mineral origin are referred to as asbestos. The term asbestos is used to define a series of naturally occurring minerals with a morphology similar to a fiber. These minerals, with a serpentine-shaped structure, have the chemical formulation X_2-$3Si_2O_5(OH)_4$ where X can be one of the following elements, Mg, Fe, Ni, Al, Zn or Mn. Typically, an amphibole mineral has a long crystalline structure with monoclinic crystals (Mahltig & Pastore, 2018).

The fibers are obtained by crushing the rocks where they are contained, followed by a sieving and carding phase to isolate the fibers. Mineral fibers range in length from 1 to 10 cm, most commonly appearing in bundles with diameters on the order of a millimetre (Mahltig & Pastore, 2018).

This type of fiber was widely used as acoustic and thermal insulation or as reinforcement applications in 20th century buildings, however, after it was proven that inhaling these particles had serious consequences for health, its use fell into disuse and, in some cases prohibited (Mahltig & Pastore, 2018).

1.2 Animal Fibers

Fibers of animal origin have a proteinaceous nature and result from the condensation of several amino acids, which act as monomers. The type of amino acid and the degree of polymerization that they confer to the fiber ‘s polymeric chain directly contribute to its properties. The two main sources of fibers of protein origin are the fur that covers the body of various animals, wool being the most common example, and also segregations, as is the case of silk that is extracted from the cocoons of *Bombyx larvae. Mori.* Wool fiber is essentially made up of the protein keratin, which is a very complex protein and its bonds are highly cross-linked with other residual amino acids. On the other hand, silk is composed of simpler polymer chains, which are arranged in a linear structure with several hydrogen bonds (Babu, 2015).

Fibers of animal origin are characterized by having moderate resistance, resilience and elasticity and great absorbency. They are also prone to discoloration from sunlight. In nature there is an abundance of materials with structural capabilities that have reached great levels of efficiency through natural selection. Silks, most commonly found in silkworms but also in various spiders, are extremely extensible and have considerable mechanical properties, combining breaking stresses in the order of 1 to 5 GPa with deformations between 25 and 45% (Babu, 2015).

1.3 Plant Fibers

There is a wide variety of plant fibers with different chemical, physical and mechanical properties. The natural plant fibers and fillers, which may or may not come from waste, and which the specialized literature presents as potential materials to serve as polymer reinforcement are: sisal, coconut, jute, ramie, sugarcane bagasse fiber, curaua, soy, kenaf, stay, hemp, starches, wood waste, husk of rice, wheat and other cereals (Mattoso et al, 1999).

Fibers are extracted from plants and the main polymer in their constitution is cellulose ($nC_6H_{10}O_5$), where the n represents the number of times the monomer is repeated (Yu, 2015). Due to their high cellulose content, they are characterized as cellulosic. Usually, in this type of fiber there is another phenolic polymer, lignin, which serves to agglomerate the cellulose fibrils. That said, plant fibers can also be called lignocellulosic, with the exception of fibers from cotton that do not contain lignin in their composition (Aranguren et al, 2016). Of all known plant species, only a very small number of species are commercially exploited for fiber production, the percentage of which is less than 0.1% (Yu, 2015; Aranguren et al, 2016).

The anatomical origin of the fiber is a determining factor for the final properties of the composite, which is why fibers with different origins generally have different properties and, therefore, specific fields of application. In addition to this parameter, the species, age, history of the plant, cultivation conditions, climatic conditions and extraction techniques are key factors for their final properties (Romão, 2003).

Fibers can be extracted from different constituents of a plant and are therefore classified according to their origin. Practically all fibers of vegetable origin can be used as reinforcement, fibers originating from the leaf are the most used, as they are generally harder than fibers from the stem. Leaf fibers are generally known as "hard fibers" because they are rough and not very soft. Stem fibers are known as "soft fibers" as they are relatively soft and flexible (Cavalcanti, 2006). The stem fibers, which come from bundles of fibers present in the inner bark (phloem), the leaf fibers, which occur longitudinally in the leaves of certain plants in the monocotyledon group, and the seed or fruit fibers. Examples of this are linen, sisal and cotton or coconut fiber, respectively. Along with cotton, the most used vegetable fibers are flax, jute, ramie and hemp. It is possible to classify fibers of vegetable origin by their origin in the plant (Rodrigues, 2007):

- Stem fibers
  - Fibers originating from the stem are associated with the phloem vascular tissue and are made up of a single band of fibers, several layers thick, located in the external peripheral region of the central cylinder of dicotyledonous plants. These fibers run the entire length of the stem.
- Leaf fibers
  - Fibers from monocot leaves are associated with vascular tissues, which run along their entire length.
- Seed/fruit fibers
  - Cotton and coconut fibers are nothing more than epidermal hairs from seeds and fruits, respectively.

In general, the main advantages of natural plant fibers are (Marinelli, 2008):

- Vegetable fibers are renewable materials and their availability can be considered unlimited.

- Due to the enormous diversity of woody and fibrous plants found in biodiversity, there is enormous potential for the discovery of natural fibers with desirable properties (mechanical resistance, chemical and biological stability, fire resistance, lightness, resistance to abrasion and cutting, among other properties of interest).
- Vegetable fibers are less abrasive than the artificial fibers usually used as reinforcement, such as fiberglass, for example, and thus generate less wear and tear on the equipment involved in their processing.
- They are biodegradable materials, a crucial characteristic for components that are intended to be discarded after use.
- Composites reinforced with vegetable fibers, which also use biodegradable matrices, are considered the least aggressive materials to the environment and can be composted at the end of their use.
- Vegetable fibers represent a new source of income for the rural population, promoting the settlement of populations and preventing the desertification of rural areas.
- They have low density and high deformability when compared to similar materials in this field of application.
- They present low cost, in relation to the reinforcements currently used.

1.4 The Mechanical Properties of Fibers

To improve the mechanical performance and durability of composites reinforced with natural fibers, it is very important to optimize adhesion at the interface between fiber and polymer matrix as this is a key factor for this purpose. It is the quality of adhesion between fiber and matrix that allows an adequate transfer of stress to the reinforcing fibers and they are mainly responsible for the final mechanical properties. The transfer capacity at the interface and fiber/matrix adhesion depends on mechanical, electrostatic and chemical phenomena. Mechanical interconnection typically improves when the fiber surface is rougher. Chemical interconnection depends on chemical groups on the surface of the fiber and in the matrix that can react with each other to form bonds. Coupling agents can be used to act as bridges between the fiber and the matrix (Pickering et al., 2015). Among the constituents, the matrix, reinforcement and interface, it is the weakest element that determines the properties of the material, because it will be the first to cause failure in the material (usually the matrix or the interface) (Espinach et al., 2017). In this way, materials with specific characteristics can be obtained, which would not be possible with pure materials alone (Carraher Jr, 2017; Young & Lovell, 2011).

The fibrous reinforcement of a composite material consists of thousands of individual filaments with very small diameters on the order of micrometres, dispersed in the polymeric material (matrix). Typically, the mechanical properties of fibers are much higher than those of the polymer they reinforce. However, the filamentary nature of the fibers makes their direct use in structural applications impossible. The matrix is therefore responsible for not only providing a stable shape to the composites, but also ensuring the transmission of stress to the fibers and protecting their surface (Bank, 2006). In addition to these requirements, required of the matrices, the fibers must also have characteristics that allow the polymers to be reinforced effectively. The fibers must then have (Romão, 2003):

- Modulus of elasticity greater than that of the polymer to be reinforced;

- Tensile strength higher than that of the polymer to be reinforced;
- Geometry suitable for good adhesion to the matrix;
- Resistance to deterioration in contact with the matrix.

As previously mentioned, the properties of natural fibers are highly dispersed. This dispersion, considered a huge disadvantage, is due to several factors, such as in the case of plant fibers: age and history of the plant, type of soil and fertilizers used, fiber extraction process, geographical origin, cultivation conditions (humidity and temperature), degree of plant maturity and harvest time (Kaith & Kaur, 2011, Mohanty et al, 2005).

The benefits and limitations arising from the use of plant fibers as reinforcement of polymeric materials are intrinsically related to their physical and chemical properties. In terms of mechanical properties, natural fibers have a disadvantage in relation to non-natural fibers, namely the variability of mechanical properties, which are dependent on the origin of the fiber and the type of treatment required to obtain it. Table 1 presents the values of some mechanical properties of fibers that illustrate the variability present in them.

In the 1970s and 1980s, synthetic fibers largely supplanted natural fibers because of their superior performance and relatively low cost. However, in the past 15–20 years, there has been a resurgence in the use of natural fibers. This renewed interest is driven by the growing need for sustainable industrial processes, leading to an increased utilization of natural fibers (Furtado, 2009). According to Eichlorn, fibers of vegetable origin are the most commercialized fibers, among them linen and jute fibers (*Corchorus capsularis*) (Alves, 2009).

According to Christian Gschwandtner's report "Outlook on global Fiber Demand and Suppy 2023" (Gschwandtner, 2022), in 1970 the global fiber demand totalled 27 million tons, increasing 21 million tons until 1995 and 65 million tons until 2021, despite the decrease of fiber demand during the Covid Pandemic period. In the report, the author expects that the fiber consumption will reach 142 million tons in 2023. Being sustainability the main concern worldwide, with this increase in fiber consumption, this demonstrates that usage of natural fibers needs to gain more significance and replace the synthetic fibers whenever possible. Therefore, in order to understand the importance of natural fibers, this paper focuses on the growing importance of natural fibers among the scientific community, namely understanding the growth and number of publications since 2000.

2 Methodology

The implemented methodology concerned two separate stages. The first stage related to the search to update review papers to identify the existing "types" of natural fibers. Once this search was performed and the natural fibers identified, the next stage focused on identifying the number of publications per year of that same fiber.

The search was performed on the Scopus Platform only in the following fields "Title", "Abstract" and "Keywords". The search words was composed of both the "name" + "fiber". A year filter between 2000 and 2023 and additional filters of "English" and "Journal Papers" was applied for this research.

Table 1. Mechanical Properties of Natural Fibers (Bledzki & Gassan, 1999; Eichhorn et al., 2001; Moura et al, 2005; Mwaikambo, 2006; Eichhorn et al, 2009; Ku et al., 2011; Ahmad et al., 2015; Gurunathan et al., 2015; Leite, 2017; Elfaleh et al 2023).

Fiber source	Density (g/cm3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Abaca	1.5	220–980	3–12	3–10
Abaca leaf fiber	-	418–486	12–13.8	-
Agave	-	-	-	-
Alfa	1.4	188–308	18–25	1.5–2.4
Aramid	1.4	3000–3150	63–70	2.5–3.7
Bagasse	-	290	11	-
Bamboo	0.6–11	140–230	11–17	-
Banana	1.35	350–980	12–33.8	3–53
Carbon	1.4	4000	23–240	1.4–1.8
Coconut or coir	-	500	2.5	20
Coconut tree leaf sheath	-	46.4	2.3	2.84
Cocount husk fiber	-	126–148	3.1–4.3	-
Coir	1.1–1.6	106–593	1.27–6	14.21–59.9
Cotton	1.5–1.6	45.5–1000	5.5–12.6	3–10
Curaua	-	170–1672	-	-
Curua		158–729	-	5
Date	-	309	11.32	2.73
Date palm	0.9–1.2	-	-	-
E-Glass	2.5	2000–3500	70	0.5–3
Elephant grass	-	185	7.40	2.5
Flax	0.6–1.5	88–1600	24–80	1.2–10
Hardwood	0.3–1.2	-	5.2–37.9	-
Hemp	1.4–1.6	310–900	30–80	1.6–6
Henequen	1.2–1.4	355–580	10.1–16.3	3–4.7
Isora	-	500–600	-	5–6
Jute	1.3–1.5	385–850	10–55	1.16–8

(*continued*)

Table 1. (*continued*)

Fiber source	Density (g/cm3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Kapok	-	45–64	1.73–2.55	2–4
Kapok (Seed)	0.38	93.3	-	-
Kenaf	0.6–1.5	215.4–1191	2.86–60	1.6–6.9
Kenaf bast fiber	-	427–519	23.1–27.1	-
Kevlar	1.44	3000	-	2.5–3.7
Kudzu	-	130–418	-	-
Nettle	-	650	38	1.7
Oil palm	0.7–1.55	-	1–9	8–25
Okra	-	184–557.3	8.9–11.8	4–8
Opefb	0.7–1.55	248	3.2	2.5
Palm	-	377	2.75	13.71
Palmyrah	-	180–215	7.7–20	7–15
Petiole bark	-	185.52	15.09	2.1
Piassava	-	134–143	1.07–4.59	7.8–21.9
Pineapple	0.8–1.6	170–1672	60–82	1–14.5
Pineapple leaf fiber	-	400–700	23.7–30.3	0.8–1.6
Rachilla	-	61.36	2.34	8.1
Rachis	-	74.26	2.31	13.5
Ramie	1.45–1.5	348–938	24.5–128	1.2–8
Ramie base fiber	-	849	28.4	-
Rice husk	1.4	19–135	0.3–2.6	-
Rice straw	-	450	26	2.2
Root	-	157	6.2	3
Roselle	-	147–184	2.76	5–8
Sansevieria cylindrica	-	585–676	0.2–11.2	11–14
Sansevieria ehrenbergil	-	278.82	9.71	2.81
Sansevieria rifasciata	-	526–598	13.5–15.3	-
Sea grass	-	453–692	3.1–3.7	13–26.6

(*continued*)

Table 1. (*continued*)

Fiber source	Density (g/cm3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
S-Glass	2.5	4570	86	2.8
Sisal	1.3–1.5	80–840	9–38	2–25
Softwood	0.3–1.5	600–1000	3.6–40	4.4
Softwood kraft	-	1000	40	4.4
Spatha	-	75.66	3.14	6
Sugar palm	1292	156.96	-	7.98
Suggar can baggasse	1.2–1.5	20–290	17–27.1	1.1
Talipot	-	143–263	9.3–13.3	2.7–5
Vakka	-	549	15.85	3.46

3 Results

From the research, 78 different types of natural fibers were identified totalling 109886 published papers during the time period, demonstrating the significance of natural fibers within the scientific committee. From the analysis of the data, Table 2 presents the main fibers that totalize 75% of the publications. In this table, only 14 natural fibers are mentioned, leaving out the remaining 64 fibers with publications. From this table it is also possible to observe that only two animal fibers (Wool and Silk) and one mineral fiber (Basalt) are mentioned, being the rest of plant origin. Figure 2 illustrates the global chart of the number of publications of the 78 fibers with a limitation barrier separating the top 14 published fibers that represent 75% of the publications. By analysing the total numbers of the publications per year (Fig. 3), it is also possible to observe the significant growth and awareness of the usage of natural fibers, meaning that natural fibers are increasing their importance. Additionally, by analysing the numbers, Fig. 4 presents the number of fibers per year in which a paper was published.

Another analysis of the data also illustrates that from the 78 fibers only the following 40 fibers (Table 3) contain publications every year during the period of 2000 and 2023. This demonstrates the importance of these fibers in scientific research in spite of their number of publications per year.

Comparing the total number of publications in the first and second decades of the 2000s for the fibers found in the research, it is observed that for both decades there is a positive skewness, with more observations in the lower values, as there is a significant number of fibers with few publications over the years (Fig. 5). The average total number of publications almost doubles from the first to the second decade, and the associated standard deviation is also higher in the second decade. In the first decade, 75% of the total number of publications is below 325, while in the second decade the third quartile of the variable corresponding to the total number of publications is equal to 894. The maximum total number of publications also increased significantly from the first to the

Table 2. Natural fibers that totalize 75% of the publications during the evaluation period.

Fiber	Number of Papers	Fiber	Number of Papers
Cotton	17561	Flax	4676
Wool	8967	Hemp	4581
Wheat	8005	Bamboo	3777
Date	6936	Maize	3685
Corn	6056	Jute	3629
Silk	5431	Coconut	2582
Basalt	4878	Barley	2204

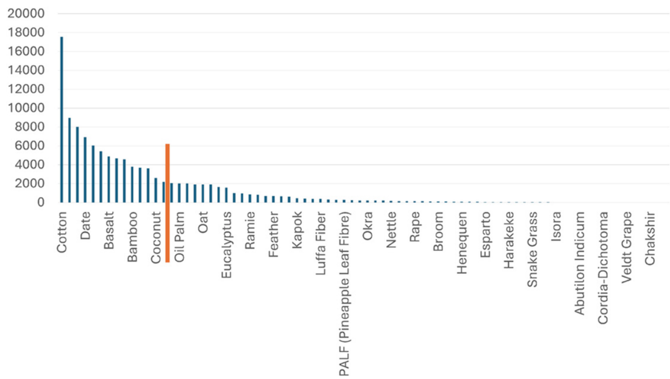

Fig. 2. Global overview of the number of publications per fiber between 2000 and 2023 with a line barrier indicating the 75% limitation of the 14 top fibers.

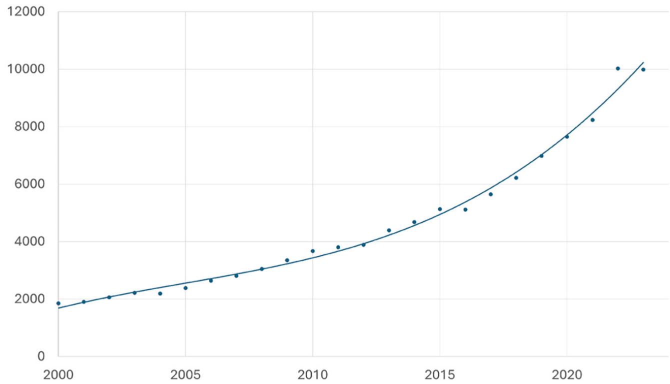

Fig. 3. Total number of publications of fibers per year.

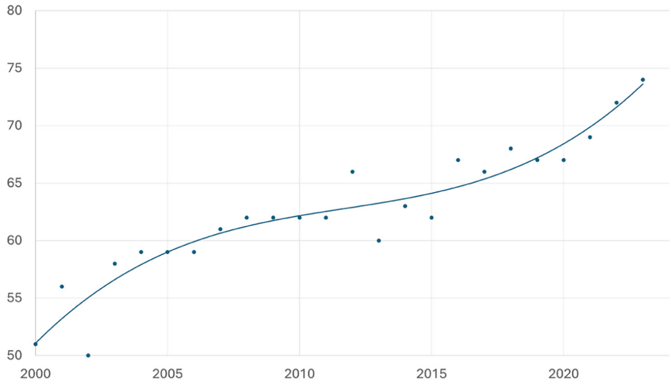

Fig. 4. Number of fibers per year which had a paper published.

second decade, rising from 5870 to 7932 (Table 4). This maximum in both decades was achieved by the cotton fiber (Fig. 5).

By conducting inference tests to determine whether the average number of publications on natural fibers increased in the last decade, it is found that, despite rejecting the normal distribution assumption for the variable of differences, a parametric test for comparing means in paired samples was performed given the sample size of 78. The test resulted in a p-value of $2.958x10^{-7}$, leading to the rejection of the equality of means at a 5% significance level. Therefore, there is statistical evidence to assert that the total number of publications on natural fibers increased in the last decade. This conclusion generalizes the observed result in the sample of fibers found to the other fibers not mentioned in this study. It can also be stated that the difference between the average total number of publications on fibers in the two decades falls within the interval] 206.4026; 444.2640 [with 95% confidence.

Analysing the annual publications of the three natural fibers with the most publications from 2000 to 2023 (Table 5), it is observed that there is a considerable difference between cotton and the others. Cotton stands out significantly, with a much higher average number of publications (731.7 compared to 33.5 for Wheat and 373.6 for Wool). Cotton also has a median value that is more than double that of the others (609.5 compared to 445.5 for Wheat and 386.8 for Wool), as well as the maximum annual number of publications, which exceeded 1300 for this fiber compared to a maximum of 665 publications for the other two fibers.

Analysing the annual publications from 2000 to 2023 for the three fibers with the highest number of publications, we observe some following trends. It can be observed that for all three fibers, the number of publications has been increasing considerably. Wool demonstrates a notable increase in publications after 2015, indicating a more pronounced growth trajectory compared to earlier years while Wheat exhibits a relatively stable trend with the increase starting nearby 2005. Cotton shows a gradual increase in publications from 2000 onwards, maintaining consistently higher values compared to the other fibers (Fig. 6).

Table 3. List of fibers with publications every year between 2000 and 2023.

Fiber	Publications	Fiber	Publications	Fiber	Publications	Fiber	Publications
Cotton	17561	Maize	3685	Coir	1635	Kapok	444
Wool	8967	Jute	3629	Eucalyptus	1585	Paper Sludge	385
Wheat	8005	Coconut	2582	Rice Straw	995	Luffa Fiber	376
Date	6936	Barley	2204	Lyocell	952	Alfa	317
Corn	6056	Sisal	2061	Ramie	862	Elephant Grass	288
Silk	5431	Oil Palm	2041	Rice Husk	836	Abaca	233
Basalt	4878	Kenaf	2024	Agave	699	Soft Wood	221
Flax	4676	Banana	1930	Feather	687	Rape	136
Hemp	4581	Oat	1916	Rye	676	Broom	117
Bamboo	3777	Bagasse	1911	Linseed	636	Alaska	106

Table 4. Descriptive Analysis of the Total Number of Fiber Publications in the 1st and 2nd Decade of the Millennium.

Decade	Mean	Sd	Min	q_1	q_2	q_3	Max
First	360.6795	840.2152	0	9.5	41	325.25	5870
Second	686.0128	1270.4622	0	17.5	108	894	7932

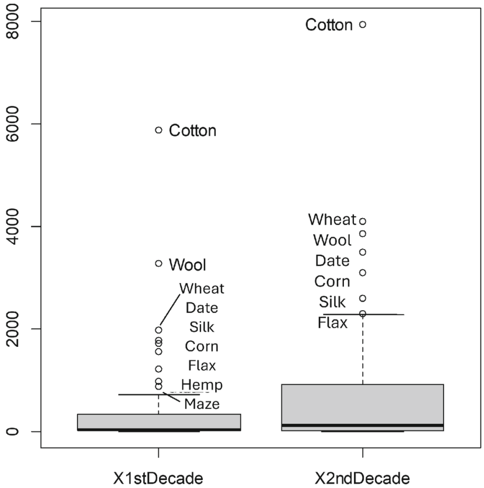

Fig. 5. Boxplot of the total number of fiber publications in the first two decades of the millennium.

Table 5. Annual publications between 2000 and 2023 for the most found researched fibers.

Decade	Mean	Min	q_1	q_2	q_3	Max
Cotton	731.7	350	582.8	609.5	850	1338
Wheat	333.5	131	167.2	304	445.5	665
Wool	373.6	247	286	343.5	386.8	665

The boxplot also illustrates the distribution of annual publications for each fiber over the period with Cotton displaying a higher median and a wider spread of annual publications compared to wheat and wool, while Wheat shows the lowest median and fewer annual publications overall. These visualizations provide insights into the publication trends over time for the three fibers, highlighting the varying growth patterns and distribution characteristics among them.

Based on the analysis of annual publications from 2000 to 2023 for the fibers with the highest number of publications, we proceed with forecasting the annual number of publications for the period from 2024 to 2028, by analysing the behaviour of the three time series, using the model ARIMA (0,1,0). Although there is an estimated increase in annual publications for all three fibers, cotton has consistently shown the highest number of annual publications and the trend suggests a continued increase in annual publications, maintaining higher values compared to wheat and wool. Wheat is anticipated to remain relatively stable with slight variations in annual publications. Wool shows a noticeable increase in publications, particularly after 2015 and it is expected to continue its upward trajectory, potentially surpassing wheat in annual publications. The 95% confidence intervals for the forecasted annual publications are wider compared to wheat, reflecting higher variability in projections (Table 6 and Fig. 7). These intervals account for the inherent variability and uncertainty in future predictions based on historical data. Even though, these forecasts provide insights into the expected trends for annual publications from 2024 to 2028, reflecting their respective growth patterns and anticipated levels of scholarly output in the upcoming years and highlighting cotton's continued dominance in publication numbers, wool's significant growth potential, and wheat's stable but lower publication output compared to the other fibers.

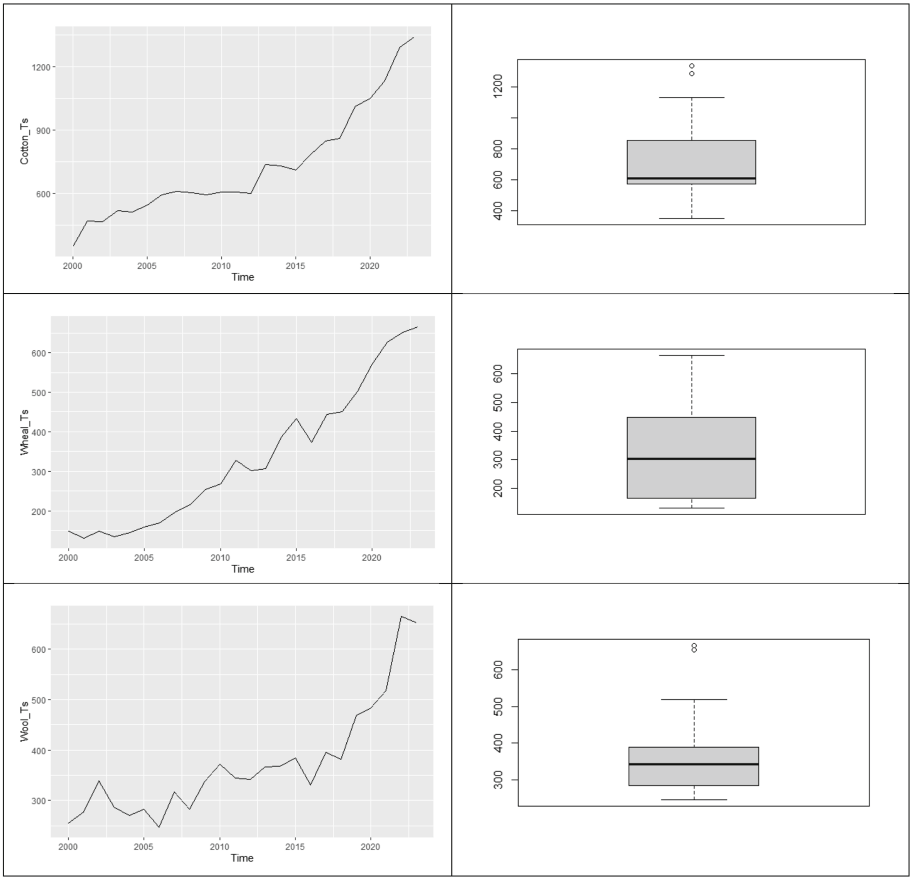

Fig. 6. Time series and boxplot of annual publications from 2000 to 2023 for the three most researched fibers.

Table 6. Forecast for annual publications from 2024 to 2028 for the most found researched fibers (2000–2023).

Year	Cotton		Wheat		Wool	
	Lo 95	**Hi 95**	**Lo 95**	**Hi 95**	**Lo 95**	**Hi 95**
2024	1274.846	1487.067	620.883	753.987	575.445	765.164
2025	1273.850	1573.976	615.751	803.988	553.458	821.760
2026	1283.080	1650.659	617.033	847.576	540.612	869.214
2027	1297.605	1722.048	621.636	887.843	532.500	911.936
2028	1315.512	1790.054	628.360	925.988	527.410	951.633

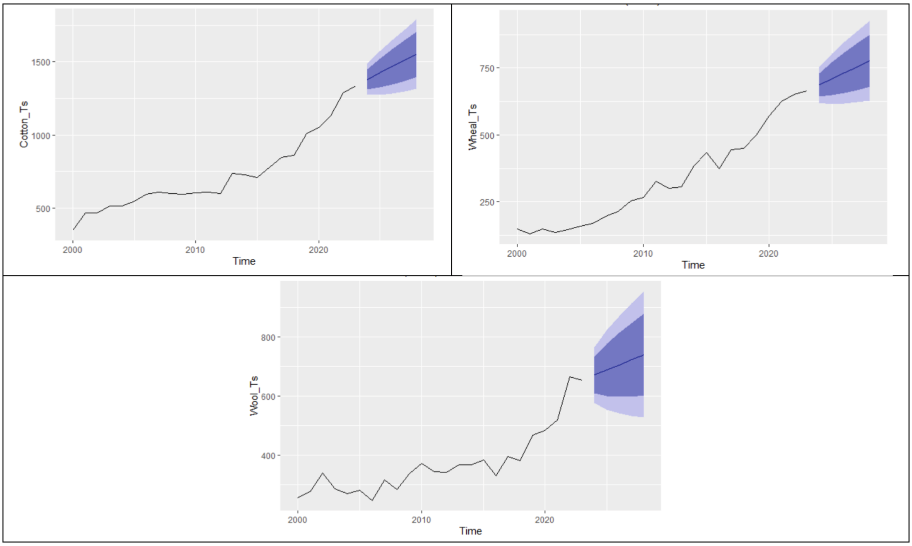

Fig. 7. The coloured area corresponds to the forecast for annual publications from 2024 to 2028 for the most found researched fibers between 2000 and 2023.

Regarding the remaining fibers within the total percentage of 25% of lowest publications, it is possible to observe from the data that there are fibers with year interval gaps between publications, in some cases reaching almost a 10 year interval. The reason for this issue may be the lack of importance towards the fiber or the difficulty in implementation of the same fiber. The interest is demonstrated by performing research of these fibers but successful case studies is required to increase its research.

Another issue from the fiber analysis, is the definition used to define the fibers. For instance, the fiber Rachilla can be from any plant. The term is defined as the stalk that bears the florets in the spikelets of grasses and similar plants, such as rushes and sedges, meaning that in the fiber analysis there is a fiber should be screened paper by paper to identify correctly the origin of the plant fiber. Another example is Kraft which is composed of cellulose material but can have its origin in several plants or be combining several plants. Within the animal fibers this issue also occurs, for example the Alaska fiber in some papers has its origin in the Musk Ox and in other papers, the fiber is related to Dall Sheep. The authors should be advised to use the correct terminology for a better understanding of fiber impact among the publications of the scientific community.

4 Conclusions

In recent years, natural fibers have achieved a promising role as reinforcing material in composites, mainly in bio-based and biodegradable polymeric matrices in a more general concept of sustainable development. Natural fibers are an abundant material, light in weight, biodegradable, economical (they are more economical than the synthetic fibers used today to reinforce composite materials such as glass fiber and aramid), have good mechanical properties and are from biomass, and are therefore promising in the area of composite reinforcement. However, there are disadvantages to its use such as low thermal stability, good moisture absorption, low compatibility with hydrophobic polymeric matrices and the quality of the fiber, as this depends on the type of processing it undergoes to obtain it, hence new fibers and applications are being developed every year. The numbers presented in this paper demonstrate this tendency and awareness of research towards the applications of natural fibers in new materials.

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Design with Spent Coffee Grounds: The Coffee Cup Project

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Abstract. Design is crucial in tackling the social, economic, and environmental challenges faced by societies worldwide. Well-designed solutions promote health, well-being, inclusivity, and sustainable development for people residing in rural, urban, and remote areas. The case study in this paper deals with a material that is considered waste, the coffee grounds. Coffee is one of the most widely consumed drinks in the world, known for its popularity and distinctive flavour. The aim is to firstly to revalue coffee grounds by transforming them into a usable resource based on a material that uses the Spent Coffee Grounds as a raw material. This transformation will be materialised through a design case study—a coffee cup. In the materialization phase, the first step begins with the 3d printing of the coffee cup so that the physical model is used to produce a silicone mould. This mould will then be used to pour the resin mixed with the coffee grounds. After undergoing the curing process, the newly designed coffee cup is removed from the mould.

Keywords: SCG using · Coffee waste · SCG valorisation · Circular economy · Product Design

1 Introduction

Design is crucial in tackling the social, economic, and environmental challenges faced by societies worldwide. Well-designed solutions promote health, well-being, inclusivity, and sustainable development for people residing in rural, urban, and remote areas (Dahner et al. 2023). Linden (2022) in one of his statements, says the following: "If design is merely an inducement to consume, then we must reject design; if architecture is merely the codifying of the bourgeois model of ownership and society, then we must reject architecture; if architecture and town planning is merely the formalization of present unjust social divisions, then we must reject town planning and its cities".

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https://doi.org/10.1007/978-3-031-80330-7_27

The case study in this manuscript deals with a material that is considered waste, the coffee grounds. Originating in Ethiopia, coffee is made from the roasted beans of the Coffea plant, and there are several varieties of beans and preparation methods, which contributes to its versatility and global appeal. Coffee is one of the most widely consumed drinks in the world, known for its popularity and distinctive flavour.

The latest figures show that Europe (CMR 2022) has the highest global coffee consumption, reaching approximately 3,252,000 tones, thus consolidating its position as the world's largest consumer. This growth is not just limited to consumption itself, but also reflects technological and social evolution, as evidenced by the rise of various brands and methods of preparing coffee, particularly the increase in the use of coffee capsules in recent years (Fig. 1).

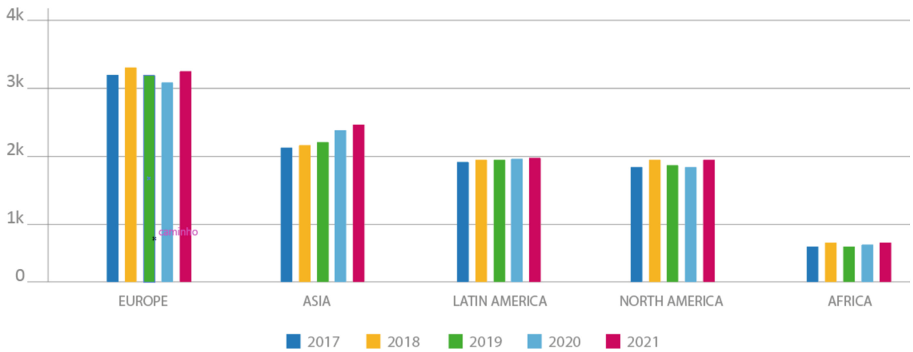

Fig. 1. Global coffee consumption per region in 1.000 tons. (*Source* Based on https://www.cbi.eu/market-information/coffee/what-demand)

The impact of coffee grounds consumption and waste in Portugal reveals an intrinsic relationship between local culture and the significant presence of coffee in consumers' social and daily lives. This phenomenon is driven by several factors, including the increasing popularity of coffee brands, emerging consumption trends and the ongoing development of caffeine culture (Oliveira and Dias 2020).

Therefore, coffee is a popular beverage with cultural and social significance worldwide. Its consumption has been steadily increasing, resulting in the generation of large amounts of solid residues in the form of Spent Coffee Grounds (SCG). According to Kourmentza et al. (2017) in recent years, there has been a growing global awareness of environmental issues which has led to research into sustainable processes and also the exploitation of waste-streams methodologies has gained interest among the scientific community. Designing sustainable solutions is necessary to support the social and human development of individuals and societies worldwide and to contribute to achieving the UN Sustainable Development Goals (SDGs). These solutions can take many forms, such as products, services, and product-service systems (Dahner et al. 2023).

The concept of Sustainable Development (SD) officially emerged in 1987 with the Brundtland report, two centuries after the Industrial Revolution. Despite criticism of its lack of clarity, the UN plays a crucial role in promoting SD at a global level. Resolution A/RES/70/1, "Transforming our world: Agenda 2030—Sustainable Development", sets out the fundamental principles and commitments for the implementation of Agenda 2030. It seeks to address global challenges through 17 Sustainable Development Goals (SDGs 2024). The agenda covers a number of goals related to eradicating poverty, promoting equality, protecting the environment and building peaceful and inclusive societies. In short, it represents a global commitment to achieving a more sustainable future.

Reflecting on the Sustainable Development Goals (SDGs), we highlight the relevance of SDG 12—Sustainable Consumption and Production—for the project. This goal aims to "ensure sustainable production and consumption patterns" (SDG 2024). In this context, the reuse of coffee grounds is a practice in line with this goal, helping to reduce waste and promote the circular economy. Papanek (1971) highlights the importance of environmental and social sustainability in design, emphasising the need to consider the impacts of design decisions on people and the planet. In turn, Chick & Micklethwaite (2013) address the role of design in promoting sustainability, emphasising cooperative social responsibility in the search for ecological and conscious solutions.

The consumption of coffee means the production of coffee grounds. So, the SCG are therefore a waste product that has already been utilised. They can be used for a wide variety of purposes beyond brewing coffee, including fertiliser, pest repellent, body scrub, odour neutraliser and natural dye (Chick and Micklethwaite 2013). SCG are already being used in various areas, including kitchen utensils (cups), such as the brands Kaffeeform, Huskee, Closca and the Gourd project.

The aim of this manuscript is firstly to revalue coffee grounds by transforming them into a usable resource based on a material that uses the Spent Coffee Grounds (SCG) as a raw material in line with the SDG-17. This transformation will be materialised through a design case study—a coffee cup. The first step begins with the 3d printing of the coffee cup so that the physical model is used to produce a silicone mould. This mould will then be used to pour the epoxy resin mixed with the coffee grounds. After undergoing the during process, the new designed coffee cup is removed from the mould.

2 Case Study of Liquid Container SCG

Today, sustainable design is intrinsic to the project itself (Manzini 2011). The creative and sustainable use of coffee waste has been an area of growing interest for companies and designers globally. Several initiatives have emerged, each with their own innovative approaches and products. The most recent examples are brands such as Kaffeeform, Huskee, Closca and the Gourd project (Fig. 2).

The company Kaffeeform (2024) produces cups and other kitchen utensils made from recycled coffee grounds. These products are durable, lightweight and have a unique appearance, providing an elegant alternative to traditional plastic or ceramic products. However, some critics point to the possible fragility of these utensils and their higher cost compared to other conventional products.

Huskee (2024) develops reusable coffee cups made from coffee. These cups have a modern aesthetic and are designed to reduce plastic waste. However, some concerns have arisen about the ability of these cups to maintain the temperature of the drink over a long period of time.

Fig. 2. Products examples of brands Kaffeeform, Huskee, Closca and Gourd project.

Closca (2024) is a company that manufactures water bottles made from recycled materials, including coffee grounds. These bottles are light, resistant and have an elegant and functional design. The core of the bottle is coated with a very flexible silicone sleeve which has also been designed to fit onto bicycles, trolleys and even handbags. Its double-opening system makes it easy to clean and allows you to insert items such as ice cubes or lemon slices, for example. It can also be fitted with an infusion accessory. The NFC chip connects the Closca water bottle to the free Closca Water App. It records your daily hydration, finds water sources and measures your positive impact on the planet.

The Gourd project (2024), organised by the company Hyo-Cup, produces coffee cups made from gourds, a natural and biodegradable alternative to disposable cups. These sustainable and ecological cups help to reduce plastic waste. However, they can be less durable than cups made from more robust materials.

Although these companies/brands and initiatives have significance and results in the field of sustainability and design, it was important to consider both the advantages and limitations of the products. Products made from coffee grounds offer an environmentally friendly alternative to conventional materials such as plastic and ceramics, but can face challenges in terms of durability, functionality and cost. In addition, the effectiveness of these products can vary depending on the production process and the additional materials used.

3 Coffee Cup Project Design

The basic methodology used was the "Double Diamond", popularised by the UK Design Council in 2005 in a report entitled "Designing the 21st Century". It is a methodology that has been widely adopted and adapted by designers and organisations around the world as an effective way of tackling complex problems and developing innovative solutions (Design Council 2005). This methodological approach comprises four stages: discover, define, develop and deliver. In the coffee cup project, the first three were used, as the final test or customer feedback had not yet taken place (Fig. 3).

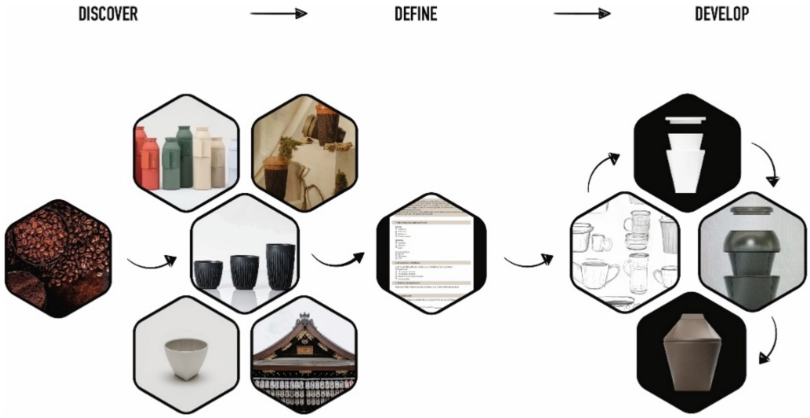

Fig. 3. Double Diamond methodology used in coffee cup project.

The discovery phase involved reflecting on a product—a coffee cup—that is used countless times in everyday life and is therefore challenging to rethink. The empathy for reusing a material that comes from coffee consumption in a coffee cup was a symbiosis that became a stimulus.

The definition relied on research into case studies already developed in the area of reusing coffee grounds in cups or glasses, cups or containers for different liquids and coffee and coffee grounds. Japanese culture, particularly its architecture, also served as inspiration. In addition, an online questionnaire was carried out with a group of users in order to understand their preferences in this area.

Development involved creating sketches to visualise the solutions in a more tangible way and then developing a 3D drawing to analyse their final form. Once the best design had been chosen, technical drawing and prototyping took place.

4 Coffee Cup Project with Spent Coffee Grounds

As mentioned before, the COPJAR design was inspired on the architecture of the Japanese culture. The digital model was then printed using an extrusion-based printer, the Ultimaker. The following figure illustrates the imported CAD files in the software controller of the 3D printer. In this Fig. 4, it is possible to observe the red colouring representing the physical model and the blue colouring the base and support to attach the part to the platform and support it's overhangs during the building process. Figure 5 illustrates the building process in the Ultimaker printer of the parts in nylon black material.

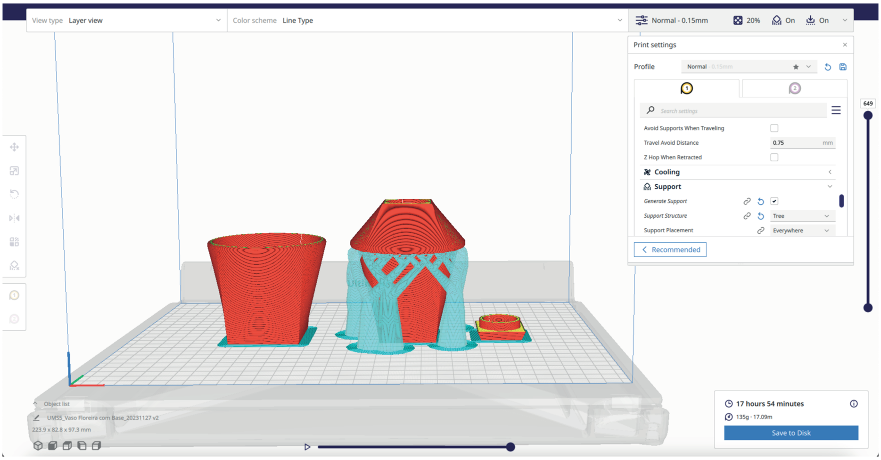

Fig. 4. Imported CAD files in the software controller of the 3D printer.

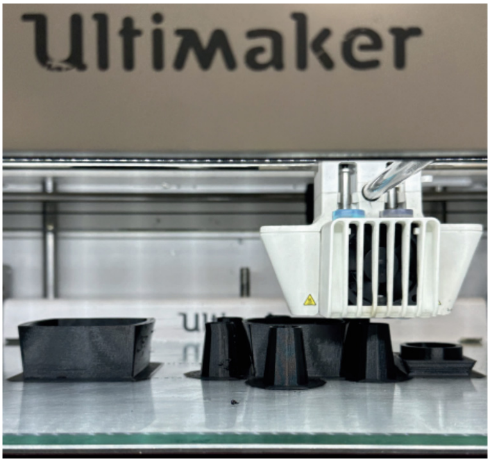

Fig. 5. The building process in the Ultimaker printer.

After removing the support structures and undergoing surface finishing operations, the coffee cup and the remaining parts where then painted and dried to obtain their final aesthetic aspect for the desired product. The physical coffee cup was then used for the next step, the materialisation of a coffee cup with coffee grounds.

In this production phase, the first step consists of producing a silicone mould, but in order to undergo this step, a structure for the mould must be produced first. In Fig. 6, on the left, it is possible to observe the carboard box that was created, the coffee cup suspended in the air by the injection channel and 4 small metallic tubes that will serve the air escape. The silicone material was obtained by mixing the Resin Biresin® G26 with the Hardener (B) Biresin® G26 in adequate proportions so that the mould may remain flexible and easy to work with. Once the mixture mas done, the mixture was poured into the mould and then placed in a vacuum system in order to remove all the air bubbles trapped with the mixture. During this process, the curing process will also begin to occur solidifying the silicone material. This step took about 24h, after which the cardboard box was removed, and the silicone mould opened. The remaining injection channel and air trap channels, along with the coffee cup were then also removed. In Fig. 6 on the right, the silicone mould is presented open with the coffee cup that was used to produce the mould.

Fig. 6. Fabrication of the mould in order to produce the silicone mould itself.

During the curing stage of the silicone mould, about 1kg of used coffee grounds was placed in an oven at 30º C in order to dry the coffee grounds during the same time period. After drying the coffee grounds, the next step consisted in obtaining a mixture of resin and coffee grounds. The mixture consisted of the same resins used to produce the silicone mould but with different proportions to harden the coffee cup (Fig. 7). An initial study was conducted where the mixtures were made with 10%, 20% and 50% of coffee grounds. The mixtures with 10% and 20% presented enough viscosity that would allow the injection of the material into the silicone mould in order to produce the new coffee cup. The 50% mixture did not exhibit the desired quality and was therefore excluded. The mixture with the highest quality, 20%, was selected. Figure 7 illustrates the three mixtures.

The final step of the materialisation of the new coffee cup design consisted of performing the mixture of 20% coffee grounds and then using an industrial syringe, injecting the mixture into the closed silicone mould. After a 3h curing process, the mould was opened, and the new coffee cup was removed from the mould. The 3D printed coffee cup and the produced coffee cup are illustrated in Fig. 8.

Fig. 7. Mixtures made with 10%, 20% and 50% of coffee grounds.

Fig. 8. The produced coffee cup on the left and the 3D printed coffee cup on the right.

5 Conclusions

The interplay between the growth of coffee consumption and ecological initiatives highlights the complexity of this scenario, highlighting the ongoing need for innovative and responsible approaches to address the challenges associated with this cultural and social dynamic.

COPJAR is an innovative drinkware set, consisting of a glass and a carafe, that actively promotes sustainable practices and integrates functionality and aesthetics in a synergistic way. Inspired by Japanese culture, especially the elegance of the utensils used in everyday life, ranging from traditional tea cups, marked by minimalism, to ornamental vases.

The main material, coffee grounds, not only adopts a sustainable approach, but also adds a unique and symbolic texture, enriching the sensory experience. The natural earthy tones pay homage to the colour palettes of Japanese ceramics, providing an organic and harmonious appearance. The sharp-shaped finishes provide distinct features, contributing to the uniqueness of the objects, integrating elegance.

The materialisation of the coffee cup in resin with coffee grounds allowed to design a novel product that needs further testing and experimentation. Even still, after a month of its production, the new coffee cup still contains a scent of coffee, allowing to produce a product associated with an aroma. This case study also demonstrates that waste if properly thought through can be used as a raw material for other products contributing to added value of that same product.

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Sustainability and Agrifood

The following section contains papers related to “Sustainability and Agrifood”.
The editors had assistance from the following conference organizing committee members in the editing of this section:

- Catarina Pereira Nobre
- Flávio Gabriel da Silva Craveiro
- Vânia Sofia Santos Ribeiro

The Attractiveness of an e-marketplace for Smallholder Farmers: Lessons from the Consumer Approach

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Abstract. One of the main strategies proposed to obtain fair prices and reduce dependence of smallholders on large food distribution companies is the development of direct sales channels by small farmers. Within the SMALLDERS project, belonging to a research call by the European Union, the aim is to develop a digital platform to sell on-line directly to the end consumer and thus improve the economic sustainability of the small farmer's business. This work includes the results of focus groups held with consumers to learn about their fresh food purchasing habits and under what conditions they would be willing to participate as buyers in a platform of this type. The results reveal that consumers are aware that farmers are not receiving fair prices for their production, and buying directly would allow them to earn a higher profit margin. However, the final willingness to participate in the platform is not high due to several factors, such as: the impossibility of seeing the purchased product directly, the large amount of product that make up the shopping baskets offered by these platforms, and the high final prices that are usually derived from the transport costs incurred.

Keywords: Focus Groups · E-commerce · Direct Sales Channel

1 Introduction

The protests of farmers and livestock farmers that have been taking place in many European Union countries since January 2024 are a clear reflection of the need to address a major transformation of the European agri-food system. In addition to the threats they have been facing for several decades, there are now new ones arising from new international trade agreements that make competition more aggressive, from investment requirements to comply with the environmental criteria established by the European Union's green legislation and policies, the increase in production costs (especially energy costs) that are not passed on to the prices charged, the greater price sensitivity of consumers due to the inflationary crisis experienced after COVID-19, or the process of depopulation and aging of the rural world that hinders access to labour and generational succession on farms.

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Smallholders are the weakest link in the agri-food supply chain and their limited bargaining power with large agri-food industries and distribution chains prevents them from receiving fair prices for their products. They are thus faced with low returns that jeopardize the economic sustainability or survival of their farms.

The challenge is to find strategies and tools that, within or outside a law governing the functioning of the agri-food chain, enable farmers to charge fair prices. One of the strategies traditionally proposed is the promotion of disintermediation through direct sales channels. This option has become more attractive as a result of the rise of e-commerce, especially since the COVID-19 pandemic (Musa et al. 2023).

In this context, the SMALLDERS research project, funded by the European Union and involving 5 partners from 4 countries, was launched: Italy, France, Spain, and Tunisia. The international SMALLDERS project aims to develop a technological platform that, through the use of innovative strategies and methodologies, new technologies and business models, will improve the resilience of small farms in the Mediterranean area, and thus cope effectively and efficiently with unexpected events and disruptions in their supply chains, such as those generated by the COVID-19 pandemic. It is a comprehensive platform, because it will integrate modules with very different objectives. From a module that will make it possible to create a greenscore of the producer and his farm according to their impacts on water consumption, soil conservation, etc., to a module for matching job supply and demand. The SMALLDERS platform will enable interaction between the different participants in the agri-food value chain, providing them with a series of resources and functionalities that will allow them to achieve their respective objectives.

One of the main goals of the SMALLDERS project is to propose innovative business models for smallholders in which small farmers will be able to develop e-commerce activities directly with the final consumer. In other words, turning the SMALLDERS platform into what is called an e-marketplace. Janita and Miranda (2013) define the e-marketplace as a way of doing business that uses Internet technology to bring together multiple buying and selling firms around a website or platform, enabling them to transact business through various mechanisms, and directed either by a neutral third party outside the exchanges that take place, or by one or more of the parties involved [buyers or sellers]. It also offers various value-added services that improve relationships between buyers and sellers. From the point of view of Business to Consumer (B2C) markets, e-marketplaces are the translation of shopping centers into the virtual world. In the case of food, it is similar to the old food markets that existed and still exist in large cities.

The rise of the Internet and social networks has given rise to a boom in e-marketplaces in both the B2C and Consumer to Consumer (C2C) spheres. The novelty and originality of the SMALLDERS platform lie in the fact that the suppliers are small agricultural producers, so that the e-marketplace becomes a process of disintermediation and a direct sales channel to the end consumer.

However, the success of this platform as a sales channel for small producers depends on its acceptance by the end consumer. A pre-analysis of the commercial viability of the e-marketplace resulting from the technological platform is necessary. For this reason, the overall goal (OG) of this study has been to qualitatively identify the level of interest of potential consumers in purchasing fresh food directly from producers through an e-marketplace. This OG was divided into the following specific objectives: SO1) to identify consumer attitudes and beliefs towards this type of fresh food shopping channel, and SO2) to identify what conditions and what requirements or features of the e-marketplace would be conducive and valuable for the consumer to register on the platform and make purchases through it.

2 Literature Review

A literature review shows that the current interest in e-marketplace platforms is reflected in the appearance of very recent research published mainly from 2020 onwards. However, their study from the consumer perspective is still very scarce and limited, in the sense that some of the articles consider as subject of analysis current users of the platform, not allowing to know the intentions and predisposition to use these platforms as a purchase channel by the standard consumer.

Thus, for example, Stephens and Barbier (2021), through a case study, describe the functioning of an e-marketplace and interview 18 French consumers to get their opinion and assessment of their participation in the e-marketplace. The study by Parth et al. (2021), conducted in India, aims to explore how a socio-digital platform can foster consumer's responsibility in food consumption to encourage sustained responsible consumption and uncovers its possible impacts on different stakeholders in the agricultural ecosystem. It is qualitative research through interviews. Yu and Zhang (2022) analyse in China a specific case of online selling that can be linked and applied through an e-marketplace platform: livestreaming. They intend to explore the influencing factors from the levels of the platform, product, and consumer that affect consumers' attitudes and purchase intentions towards agricultural products via public-interest livestreaming.

The study by Robina-Ramírez et al. (2022) was carried out in Spain with the aim of testing attributes that may influence the intention of using an e-marketplace to buy and sell organic products. Finally, the research by Liu et al. (2023) aims to focus on how the fresh e-commerce platforms can reduce consumer conversion to other forms of purchase and increase consumer repurchase. Through a survey of Chinese consumers, they argue the advantages of these type of digital platforms.

3 Methodology

As the concept of an e-marketplace platform for food shopping is practically unknown among potential consumers and there are only very few real experiences in the market, we considered that the study of consumers' predisposition towards these food shopping channel models should be based on qualitative research methods, rather than quantitative methods.

The focus group technique was chosen. Focus group discussion is frequently used as a qualitative approach to gain an in-depth understanding of social issues. It is widely used in the field of the study of food consumer behavior. In general terms, this technique consists of creating conversations among a group of people (in this case, consumers who are responsible for buying food in their households) with respect to topics that will be raised by a moderator through a semi-structured topic guide. Semi-structured questions are used to allow for open-ended responses and further discussion around specific responses.

Authors such as Kitzinger (1995) or Morgan (1996) define focus group methodology as a technique where a researcher assembles a group of individuals to discuss a specific topic, aiming to draw from the complex personal experiences, beliefs, perceptions and attitudes of the participants through a moderated interaction.

The main technical elements of the methodology used are described below:

- **Criteria for inclusion of participants**. All participants were the main or joint decision makers for food purchasing in their homes.
- **Selection of participants**. Participants were recruited through a mixture of snowball sampling and convenience sampling. Volunteers were compensated with a gift card for their participation.
- **Number of sessions and participants.** 6 sessions were organized in Badajoz (Spain), with a total participation of 41 buyers. Between 5 and 12 people participated in each session, with an average duration of approximately 2.5 h (see Fig. 1).
- **Script.** It was designed by posing the topics to be discussed in a "funnel format": from the most general questions related to food purchasing to more specific questions about an e-marketplace for small producers. Specifically, the blocks of questions were as follows:

  o Block 1: Typical establishments where fresh food is purchased.
  o Block 2: The importance of origin and sustainability in food purchasing.
  o Block 3: Direct purchase from small farmers.
  o Block 4: Internet as a purchasing channel.
  o Block 5: Online platform for small farmers.

- **Supplementary materials.** The moderators of the focus group sessions used audio-visual material to complete and explain some parts of the questions posed to the participants. Specifically, participants were shown images of various organic food labels, a real website was used to explain how the consumer groups and the box system work, another real website was also used to explain how an e-marketplace for small farmers works, and a video was shown on how the systems for sponsoring a tree or an animal work. In addition, participants filled in a quick questionnaire with basic information on their socioeconomic profile and food consumption habits (Table 1).
- **Recording of the sessions.** Focus groups were audio and video recorded for subsequent reference and to aid verbatim transcription and subsequent data analysis. Verbal consent was confirmed at the beginning of each focus group.
- **Analysis of results.** Three researchers, using the traditional approach of reading the original transcribed audio and video recordings, analysed the transcripts (Braun and Clarke 2006). From there, a content analysis, a keywords-in-context, and a discourse analysis were carried out to obtain the main results.

4 Results

The results are discussed following the 5-block structure discussed above.

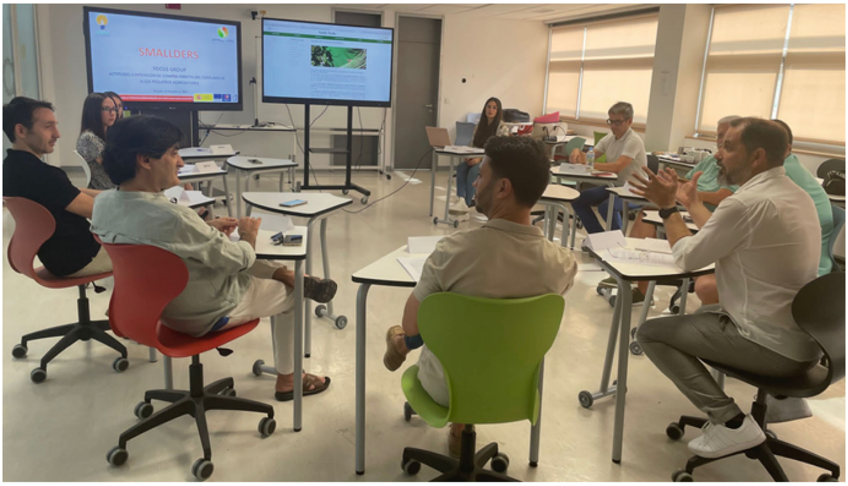

Fig. 1. A focus group session

Table 1. Participant identification questionnaire

Name	Gender	Age	Studies	Income (€/month)	Household size	Frequency of fruit and vegetables consumption
Participant 1	M	69	Secundary	2000–3500	2	Daily
Participant 2	M	55	University studies	3500–5000	2	Daily
Participant 3	M	52	University studies	2000–3500	4	Almost every day
Participant 4	M	40	University studies	> 5000	4	Daily
Participant 5	F	32	University studies	3500–5000	2	Daily
Participant 6	F	27	University studies	< 2000	1	Daily

Block 1: Typical establishments where fresh food is purchased:

- Tendency to shop in neighborhood/proximity shops when it is an almost daily purchase.
- Tendency to shop in large stores when it is a large purchase containing products from different categories, including fruits and vegetables.
- Reasons to buy fruits and vegetables in neighborhood shops: proximity, personalized service, higher quality of fruits and vegetables than in large supermarkets (at its

optimum point), quality-price balance, more varieties available, trust, local or nearby product.
- Reasons to buy fruits and vegetables in supermarkets: convenience, time saving, being able to buy the whole shopping basket in one place, freedom to choose the product you prefer based on what you see.
- Two key elements of fruits and vegetables purchasing: being able to see the product in situ (and choose it) and the price.
- Changes in consumption patterns during the pandemic, if they occurred (in few cases), have not been sustained over time.

Block 2: The importance of origin and sustainability in food purchasing:

- Diversity of views on the consideration of origin in the fruits and vegetables purchase decision
- However, if asked specifically about their preference for local products, the general response is yes, they prefer them to foreign products.
- A tendency to think of local produce as fresher and safer (food safety, treatments, etc.).
- In many cases, preference is given to local products with the aim of helping small producers and the local economy.
- Low level of awareness of what organic products mean.
- Low level of awareness of eco-labelling.
- Acceptance of organic fruits and vegetables being more expensive.
- They do not give much credibility to organic production.
- Lack of concern for the environmental impact of agriculture. In many cases, this lack of concern is associated with a lack of knowledge on the subject.
- When local origin is valued, it is for its potential impact on freshness or support for the local economy, not for its environmental and carbon footprint impact.

Block 3: Direct purchase from small farmers:

- Sporadic experiences, especially in rural environments. Not that accessible in urban settings.
- Perceived benefits of direct purchasing: elimination of intermediaries (fairer prices paid to farmers), support for the local economy, perception of fresher and higher quality products.
- They consider that the farmer will earn more margin if he sells directly. Despite this, they consider that buying directly from the farmer is more expensive. This is due to high shipping costs and because disintermediation also prevents the possibility for intermediaries to obtain advantages through economies of scale and economies of product portfolio.
- They are aware from the media of the problem of costs and low prices paid to farmers.
- They do not blame the problem on large-scale retail distribution, but on the excess of intermediaries, on the length of the distribution chain.
- They are aware that the countryside must be protected because it feeds us, but they consider that consumer has no power to influence positive changes.
- Few consumers identify buying directly from the farmer with non-personal benefits, confirming that the fruits and vegetables buyer has a self-centered and selfish purchasing behavior. There are few references to support for the local economy, nor to

environmental benefits, and reference to fair prices is only mentioned when expressly asked but considering that the consumer has no influence.

- Regarding consumer groups, most consumers are aware of their existence, but with very little knowledge of how they work. They identify these consumer groups with clear disadvantages: perception of expensive, inconvenience of delivery or collection, too much quantity in each order, problems caused by baskets/boxes of a single product or by the obligation to receive pre-set products even if they do not like them, mistrust/fear of the final quality of the product.

Block 4: Internet as a purchasing channel:

- Customers are used to buying almost all types of products online, due to convenience and price.
- Increasing trend of online shopping since the COVID19 pandemic.
- Fruits and vegetables and fresh food in general are the exception. Main reasons: not trusting the quality of the product you receive, lack of personal attention, high prices.

Block 5: Online platform for small farmers:

- The idea is considered as a good one, but the prices must be competitive (compared to what is found in corner shops and supermarkets).
- Clear barriers to entry (to subscribe or try it out) are identified:

  Distrust about the quality and condition in which your fruits and vegetables order will arrive. They do not associate it with products that are fresher than what they can buy on the spot in a corner shop.
  Not having the product at the time of purchase (high delivery times). In this product category, purchases tend to be daily purchases aimed at meeting immediate needs.
  Too much product in a single purchase.
  Lack of variety in products and boxes.
  Doubts about the shipping costs and the final price you get for your purchase.
  Lack of personal contact, although they generally see this as sufficiently compensated for by the information provided by producers.

- It is perceived as more focused on large consumers (understood as families, households with 4 or more members, or even restaurants) than on small households.
- Regarding platform attributes:

  They attach importance to the platform including opinions and ratings from other consumers.
  Information on the traceability of the product is important.
  Information on the origin of the products (highlighting local or regional origin) would be of value to them.
  They find the option of creating multi-product and multi-producer boxes attractive.

- The same disadvantages are attributed to the adoption/sponsorship system. It may be an option if it is marketed as a “gift” (e.g. give a vineyard as a present).

- They do not attribute value to the possibility of visiting the farm and carrying out complementary activities. It is not an incentive to try the product or subscribe to the platform.
- Visiting and agricultural activities would be more focused on families with young children.

5 Conclusions

The qualitative research conducted allow us to conclude that there is a low consumer acceptance of the use of an e-marketplace platform for small-scale farmers. The problem is not the platform itself, but the way of buying fresh products, especially fruit and vegetables. In order to minimize consumers' reluctance to use this type of platform, a series of specific recommendations are set out below on the functionalities to be included in the e-marketplace platform from the consumers' point of view. The recommendations are grouped according to their strategic importance into two types: recommendations for key actions and recommendations for complementary actions.

Key actions (product policy):

1. Consider the use of small quantity boxes/baskets, adapted to the size of small households.
2. Consider the use of multi-product boxes/baskets. Encourage associations between nearby producers for joint sales.

Key actions (communication and promotion policy):

1. Design clear messages about the freshness of the fruit and vegetables delivered, highlighting them in an attractive way and in an attractive place on the website.
2. Highlight the local and regional origin of the products, as well as design messages to support the local/regional economy. It would be advisable to include in the platform the option of using the buyer's location to offer products of nearby origin.
3. Preferably highlight personal benefits for the shopper and, secondarily, environmental and social benefits. These benefits would focus on the quality of the product and its freshness (time of harvest and delivery time), positioning it as something that cannot be found in large supermarkets or neighborhood shops. It is also possible to play with the healthy positioning of fruit and vegetable consumers. The link that exists for the consumer between organic foods and health must be exploited. According to research on the consumption of organic foods, the healthy factor has more weight than the protection of the soil itself or the contribution to the fight against climate change. Technical information on the environmental impact of an agricultural operation must be incorporated to convey credibility, but it must be communicated using the priorities of the end consumer (health) and their own language. The consumer does not have the knowledge or interest to exclusively value technical environmental information.

Complementary actions:

1. It is recommended to include videos showing the products. For instance, videos showing the preparation of a real order to appreciate the process and the quality of the fruit and vegetables included. The positive impact on the consumer of including photos and videos of the products is very clear.

2. Create an order return or compensation system to give consumers more peace of mind.
3. Include a section to collect opinions and evaluations from other users.
4. Include an instant response chat to resolve possible doubts that may arise for the consumer regarding the order, thus avoiding leaks during the purchasing process.
5. Include forms for direct contact with farmers to resolve doubts about products, shipments and other aspects related to orders.
6. Include the option to save pre-selected product lists for future purchases based on previous purchases, thus increasing the speed of product selection during the purchase process.
7. Create mechanisms (promotions, offers) to incentivize the first purchase and/or registration on the platform to build trust.

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Nutritional Composition and Bioactive Content in Various Traditional Portuguese Vegetable Soups

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Abstract. The Mediterranean diet is renowned for its health benefits, including protection against diseases such as heart disease and cancer. Soups, with their nutritious ingredients and versatile nature, align perfectly with this diet. They offer a delicious and comforting eating experience while providing essential nutrients. Soups can be customized to fit various dietary needs and preferences, making them suitable for any meal or occasion. In this study, quality characteristics were typified in 16 Portuguese traditional soups. The nutritional composition, total phenolic content and antioxidant activity of the soups were analyzed and compared. Proximate analysis was carried out in accordance with the Association of Official Analytical Chemists methods. Antioxidant activity was determined using the DPPH method and total polyphenol content using the Folin-Ciocalteu method. The total antioxidant capacity ranged from 235.8 to 1410.2 µmol Trolox equivalents (TE) per 100 g, while the total phenolic content ranged from 16.2 to 52.0 mg gallic acid equivalents (GAE) per 100 g. The results demonstrated that the antioxidant and phenolic content was higher in soups containing pulses or broccoli. The data also indicate that vegetable soups can contribute significantly to the recommended daily intake of nutrients and vegetables.

Keywords: Mediterranean vegetable soup · Quality characteristics · Nutritional composition · Bioactive compounds

1 Introduction

The Mediterranean diet is believed to protect against various diseases, such as coronary heart disease, stroke, neurological disorders, cholesterol reduction, and cancer risk [1, 2]. Oxidative stress, which results from an imbalance between free radical generation and

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antioxidant defense in tissues, is recognized as a key factor in the onset and progression of many age-related diseases [3]. Bioactive compounds found in plants, such as carotenoids, flavonoids, phenolics, as well as antioxidant vitamins C, A, and E, along with other micronutrients, may contribute to protection against oxidative stress [4].

The Mediterranean diet is not only a type of food but also a lifestyle that includes certain habits that contribute to good health and longevity. An example of this is the preference for local and seasonal products, which contribute to sustainability and social interaction during meals and their preparation. This has a positive impact on social life, happiness, and well-being [5].

Soups are a natural fit within the Mediterranean diet, which emphasizes fresh, whole foods and healthy fats. Examining the alignment of soups with the principles of the Mediterranean diet. Soups are a great source of nutrition as they contain a variety of ingredients such as vegetables, lean proteins, whole grains, and legumes. These ingredients provide essential vitamins, minerals, fiber, and protein that contribute to overall health and well-being. Additionally, soups can be customized to fit specific dietary needs, making them suitable for a wide range of nutritional preferences and requirements [6].

Beyond their nutritional value, soups offer a delicious and comforting eating experience. The combination of carefully selected ingredients, herbs, spices, and seasonings creates rich and complex flavor profiles that appeal to the taste buds. Enjoying a warm bowl of soup can evoke feelings of satisfaction and contentment, promoting overall well-being. Soups can be easily adapted to suit different tastes, cultural preferences, and seasonal ingredients, allowing cooks to experiment with flavors and textures. They can be prepared in countless variations, from light broths to thick stews. Additionally, soups can be served as appetizers, main courses or even desserts, making them suitable for any mealtime or occasion. During colder months or when individuals are feeling unwell, soup can have a soothing and comforting effect due to its warmth and aroma.

In Portuguese cuisine, soups play a prominent role and are cherished for their rich flavors, hearty ingredients, and comforting qualities, reflecting both the culinary tradition and the emphasis on fresh, local ingredients. Some of the notable types of vegetable soups commonly found Portuguese cuisine are “Caldo Verde” and “Sopa de Feijão”. However, it should be noted that the health benefits and nutritional characteristics of these vegetable soup products have not yet been evaluated. It is important to evaluate the health benefits of soup products and their nutritional characteristics.

The objective of this study was to analyze 16 soups from ‘Sopas Graciete’ company, classified as soup base or nourishing soup. The study included bromatological characterization, determination of biologically active phytochemical compounds (total phenolic compounds and antioxidant activity). The bromatological characterization involved determining moisture, ash, protein, fat, crude fiber and calculating the non-nitrogenous extract.

2 Material and Methods

2.1 Soup Samples

As part of the DM4You project, 16 soups made by Vasco, Nuno & Cláudio Vieira, Lda. Company (Sopas Graciete) were analyzed. The vegetable formulation of these soups is shown in Table 1. Based on their formulation, the company categorized the soups as Nutritious and Basic.

2.2 Quality Analysis

2.2.1 Proximate Analysis of Vegetable Soups

The proximate analysis of 16 samples was conducted following the methods of the AOAC standard methods [7]. This included determining the moisture content (MC%) through desiccation using an infrared lamp on a Sartorius MA 30 balance, ash content through dry incineration, protein content using the Kjeldahl method, fat content through Soxhlet extraction, and crude fiber through the FOSS Fibertec 8000 equipment according to the standard [8]. The non-nitrogenous extract was obtained by subtracting all previously determined contents from the total (100%). Quadruplicates were made per sample.

2.2.2 Phytochemical Evaluation

The biologically active phytochemical compounds were evaluated based on their total phenolic content (TPC) using the Folin-Ciocalteu method (mg GAE/100 g product) [9] and their antioxidant capacity (AC) using the DPPH method (μmol TE/100 g product) [10]. Triplicates were made per sample.

2.2.3 Statistical Analysis

The statistical analysis was performed by using StatisticaTM v8.0 software from StatSoft [11]. Data were subjected to one-way or factorial ANOVA, and the means were compared using the Tukey HSD test ($p = 0.05$).

3 Results

The chemical composition of the 16 soups samples according to their type, *Basic* soups and *Nutritious* soups, are presented in tables 2 and 3, respectively.

The mean values (%) of the moisture, protein, ash, fat, crude fiber and non-nitrogenous extracts of the 9 basic soups were found to be 93.9%, 1.0, 0.6, 0.5, 0.4 and 3.5, respectively in dry weight (Table 2). The results were homogeneous with low coefficients of variation for each component.

Table 3 presents the results of the composition analysis of the Nutritious soups. The data shows that the soups contain an average of 90.0% water, 6.2% non-nitrogenous extracts, 1.8% protein, 0.6% ash, 0.7% fat and 0.6% crude fiber.

The analysis of variance was conducted to compare the composition of two types of soup (nutritious *vs* basic) as an independent variable (Table 4). The results showed

Table 1. Categorization and vegetable formulation of the 16 soups.

Soup Nº	Basic formulation	Garrison formulation	Typology
A	butter beans, potatoes, carrot, onion, garlic, coriander, olive oil, salt	butter beans, carrots, cabbage, turnip	Nutritive
B	potato, carrot, onion, garlic, coriander, olive oil, salt		Basic
C	potato, carrot, onion, garlic, olive oil, salt	green beans, carrot laminated, cabbage	Basic
D	butter beans, potatoes, carrot, onion, garlic, coriander, olive oil, salt	spinach	Nutritive
E	butter beans, carrots, onion, garlic, leek, olive oil and salt	butterbeans and cabbage	Nutritive
F	potato, carrot, onion, garlic, olive oil, salt	green beans, carrots laminated	Basic
G	potatoes, carrots, onion, garlic, olive oil, salt	watercress	Basic
H	potatoes, carrots, onions, garlic, courgette, pumpkin, turnip, leek, parsley, olive oil, salt		Basic
I	chickpeas, potatoes, carrots, onions, garlic, coriander, olive oil, salt	chickpeas and spinach	Nutritive
J	chickpeas, potatoes, carrots, onions, garlic, pumpkin, olive oil, salt	bread, green beans, carrot, turnip and mint	Nutritive
K	potatoes, carrots, onions, garlic, courgette, leek, coriander, olive oil, salt	Portuguese cabbage	Nutritive
L	potato, carrot, onion, garlic, olive oil, salt		Basic
M	peas, potatoes, carrots, onion, garlic olive oil and salt		Nutritive
N	potato, carrot, onion, garlic, courgette, pumpkin, olive oil, salt		Basic

(*continued*)

significant differences between the two groups in terms of their macronutrient composition, except for the ash content. The base soups had higher moisture content, while the

Table 1. (*continued*)

Soup Nº	Basic formulation	Garrison formulation	Typology
O	broccoli, onion, garlic, courgette, pumpkin, leek, coriander, olive oil, salt		Basic
P	cauliflower, carrots, onions, garlic, turnip, coriander, olive oil, salt, pepper		Basic

nutritious soups had higher contents of non-nitrogenous extracts, protein, fat and crude fiber.

The analysis of variance, which used the sixteen types of soup as the independent variable (refer to Table 5), showed significant differences for all macronutrients. However, the means did not always fit the soups into the groups initially defined. For instance, soups D and K have protein and crude fiber values that are more similar to the base soups.

The macronutrient values of the 16 soups were compared with public labels and with values obtained from the ingredients supplied by tables of theoretical data [12]. The discrepancies observed were considered normal, as each bowl of soup, even if homogenized, can have varying amounts of garnish (ingredients in suspension), which alters its composition.

The results of the total phenolic content (TPC) and antioxidant capacity (AC) of the 16 soup samples in terms of biologically active phytochemicals are shown in Figs. 1 and 2, respectively.

Based on the provided data, soup O, consisting of ingredients such as broccoli, onion, garlic, courgetti, pumpkin, leek, and coriander, exhibits the highest TPC at approximately 53 mg EAG/100g product. In contrast, soups B and C demonstrate the lowest TPC values, approximately 16 mg EAG/100g product. Additionally, soup A displays the highest antioxidant capacity at around 1400 μmol ET/100 g, whereas soup C exhibits the lowest antioxidant capacity at approximately 239 μmol ET/100 g. The ingredients in soup A are renowned for their abundance of phenolic compounds, recognized for their potent antioxidant properties.

The recommendations of health organizations [13, 14] are an intake of at least 400 g of vegetables a day to reduce the risk of developing non-communicable diseases (protective against cardiovascular disease and certain cancers) and to help to ensure a sufficient daily intake of dietary fiber. Despite the nutritious benefits and the epidemiological evidence of consuming vegetables, a significant majority of consumers still do not reach the recommendations of health organizations so the vegetables soups could be an alternative to consumption for its ease of preparation and preservation.

Table 2. Chemical composition of *Basic* soups.

Soup Nº	Moisture content (%)		Protein (%)		Ash (%)		Fat (%)		Crude Fiber (%)		Non-nitrogenous extract (%)	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
B	94.82	0.00	0.80	0.06	0.71	0.01	0.669	0.04	0.48	0.01	2.50	0.09
C	93.45	0.03	0.85	0.04	0.65	0.02	0.36	0.05	0.34	0.01	4.35	0.09
F	93.30	0.01	0.94	0.02	0.60	0.02	0.35	0.01	0.40	0.02	4.41	0.04
G	94.11	0.09	0.85	0.06	0.59	0.03	0.46	0.01	0.41	0.00	3.59	0.05
H	92.41	0.00	0.94	0.06	0.69	0.00	0.73	0.04	0.54	0.07	4.71	0.11
L	92.93	0.14	0.91	0.05	0.66	0.01	0.29	0.00	0.38	0.00	4.84	0.13
N	93.32	0.05	0.97	0.11	0.66	0.01	0.36	0.04	0.43	0.01	4.27	0.11
O	95.39	0.02	1.40	0.01	0.64	0.01	0.68	0.00	0.56	0.01	1.32	0.03
P	95.43	0.01	1.09	0.04	0.64	0.07	0.57	0.03	0.51	0.01	1.76	0.08
Mean (%)	93.90	0.03	0.97	0.05	0.65	0.02	0.50	0.02	0.45	0.02	3.53	0.08
Cv (%)	0.03		5.1		3.1		4.0		4.4		2.3	

Triplicates were made per sample; cv- coefficients of variation; sd- standard deviation.

Table 3. The chemical composition of *Nutritious* soups.

Soup Nº	Moisture content (%)		Protein (%)		Ash (%)		Fat (%)		Crude Fiber (%)		Non-nitrogenous extract (%)	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
A	88.66	0.02	2.01	0.09	0.82	0.01	0.77	0.10	0.65	0.04	7.09	0.01
D	91.61	0.01	1.40	0.04	0.82	0.01	0.51	0.01	0.55	0.02	5.12	0.04
E	89.88	0.01	2.06	0.05	0.58	0.02	0.65	0.01	0.82	0.00	6.01	0.06
I	87.38	0.02	2.43	0.11	0.57	0.01	1.15	0.04	0.68	0.04	7.79	0.10
J	89.27	0.01	1.90	0.02	0.65	0.04	1.25	0.01	0.68	0.01	6.26	0.02
K	92.10	0.02	1.03	0.02	0.65	0.01	0.14	0.01	0.31	0.02	5.78	0.03
M	90.97	0.04	1.85	0.12	0.47	0.00	0.31	0.00	0.69	0.02	5.71	0.02
Mean (%)	89.98	0.02	1.81	0.06	0.65	0.01	0.68	0.02	0.62	0.02	6.25	0.04
Cv (%)	0.02		3.3		1.5		2.9		3.2		0.6	

Triplicates were made per sample; cv- coefficients of variation; sd- standard deviation.

Table 4. Analysis of variance (*F* values) and comparison of the means of the macronutrient concentrations of the *Basic* and *Nutritional* soups. N = 64.

Typology	Moisture content (%)	Protein (%)	Ash (%)	Fat (%)	Crude Fiber (%)	Non-nitrogenous extract (%)
Basic	93.90^{a}	0.97^{b}	0.65^{a}	0.50^{b}	0.45^{b}	3.53^{b}
Nutritive	89.98^{b}	1.81^{a}	0.65^{a}	0.68^{a}	0.62^{a}	6.25^{a}
F	141***	107***	0.01^{ns}	6.7*	35***	92***

ns: not significant; *, **, ***: significant at 5%, 1%, 0.1% respectively.
Different letters indicate statistically significant differences according to Tukey's test.

Table 5. Analysis of variance (*F* values) and comparison of means for the concentrations of macronutrient concentrations of the 16 soups. N = 16 x 4 rep = 64.

Soup Nº	Moisture content (%)	Protein (%)	Ash (%)	Fat (%)	Crude Fiber (%)	Non-nitrogenous extract (%)
A	86.66^{m}	2.01^{bc}	0.82^{a}	0.77^{c}	0.65^{b}	7.09^{b}
B	94.82^{b}	0.80^{g}	0.71^{b}	0.69^{cd}	0.48de	2.50^{j}
C	93.45^{d}	0.85fg	0.65^{cde}	0.36^{h}	0.34gh	4.35^{h}
D	91.6^{1i}	1.40^{d}	0.82^{a}	0.51^{fg}	0.55^{c}	5.12^{f}
E	89.88^{k}	2.06^{b}	0.58^{f}	0.65^{de}	0.82^{a}	6.01^{d}
F	93.30^{e}	0.94^{efg}	0.60^{def}	0.35^{h}	0.40^{f}	4.41^{h}
G	94.11^{c}	0.85^{fg}	0.59^{ef}	0.46^{g}	0.41^{f}	3.59^{i}
H	92.41^{g}	0.94^{efg}	0.69^{bc}	0.73^{cd}	0.54^{cd}	4.71^{g}
I	87.38^{n}	2.43^{a}	0.57^{f}	1.15^{b}	0,68^{b}	7.79^{a}
J	89.27^{l}	1.90^{bc}	0.65^{cde}	1.25^{a}	0.68^{b}	6.26^{c}
K	92.10^{h}	1.03^{ef}	0.65^{cde}	0.14^{i}	0.31^{h}	5.78^{e}
L	92.93^{f}	0.91^{efg}	0.66^{bcd}	0.29^{h}	0.38^{fg}	4.84^{g}
M	90.97^{j}	1.85^{c}	0.47^{g}	0.31^{h}	0.69^{b}	5.71^{e}
N	93.32^{e}	0.97^{efg}	0.66^{bcd}	0.36^{h}	0.43^{ef}	4.27^{h}
O	95.39^{a}	1.40^{d}	0.64^{cde}	0.68^{cd}	0.56^{c}	1.32^{l}
P	95.43a	1.09^{e}	0.64^{cdef}	0.57^{ef}	0.51^{cd}	1.76^{k}
F	15866***	203***	47***	290***	148***	2459***

ns: not significant; *, **, ***: significant at 5%, 1%, 0.1% respectively.
Different letters indicate statistically significant differences according to Tukey's test.

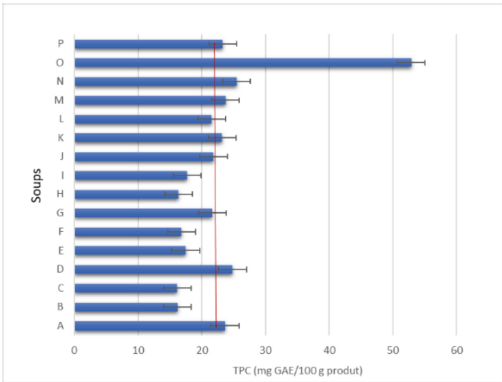

Fig. 1. - Total phenolic content (TPC) of the soup samples. The red line corresponds to the average CFT value of the soups.

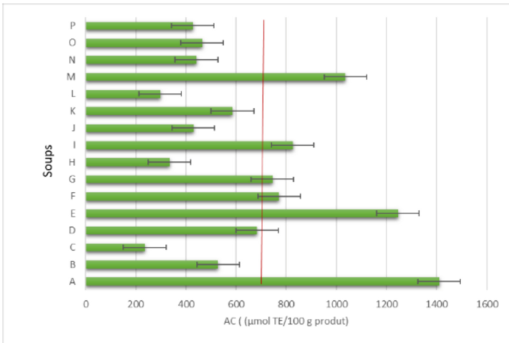

Fig. 2. - Antioxidant capacity (AC) of the soup samples. The red line corresponds to the average AC value of the soups.

4 Conclusions

The results confirm that nutritious soups contain higher levels of protein, non-nitrogenous extracts and crude fiber compared to basic soups. Significant differences in composition between the groups considered were shown by the statistical analysis. Soup D and L were the most different from the initial classification. However, an adjustment of the recipe to a higher concentration of beans would correct the problem in soup D.

As expected, the results also indicate that the variability in total phenolic content and antioxidant capacity among the different soups tested is influenced by the ingredients and their concentrations. These findings also underscore the importance of ingredient selection and composition in determining the antioxidant properties of soups, with implications for their potential health benefits.

More studies should be conducted to further explore the potential health benefits of soups and their individual ingredients. Research could focus on investigating the specific mechanisms through which soup consumption contributes to overall health, such as its impact on inflammation, cardiovascular health, and digestion. Additionally, studies could delve deeper into the bioavailability of nutrients in soups and how different cooking methods and ingredient combinations affect nutrient retention and absorption. Furthermore, research exploring the effects of soups on specific population groups, such as children, elderly individuals, and individuals with chronic conditions, could provide valuable insights into their nutritional needs and dietary preferences. Overall, continued research in this area could help promote the inclusion of soups as part of a balanced and nutritious diet.

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Barriers and Facilitators to Improve Short Food Supply Chains to Schools in Alto Minho: Multi-Actor Approach

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Abstract. In recent years, the problem of healthy eating and access to quality food has become one of the main challenges for societies around the world. We are increasingly aware that our eating habits have an impact on health, quality of life and the environment. However, various factors such as climate change - higher temperatures, drought, increased flooding, extreme events, rise in sea levels; resource depletion - oil, gas, coal, phosphorus, soil, water; food-related ill health and pressures on food supply due to population growth are vulnerabilities to the food system. New models for food production and distribution based on agro-ecological approaches are needed. Short food supply chains have emerged to respond to these challenges. The main goal of this study is to identify the barriers and facilitators for the implementation of Short Food Supply Chains (SFSCs) to schools's canteens. Multi-actor approach and engagement strategy were adopted. Furthermore, based on information gathered from interviews with regional food system stakeholders, we will analyze the strengths, weaknesses, opportunities and threats and policies relating to the SFSCs. To expand our research agenda, we highlight the potential that short food supply chains have to promote local, fresh and seasonal eating, improving healthy eating habits and the sustainability of territories. This study identifies key needs or instruments needed to implement SFSCs.

Keywords: Short Food Supply Chains (SFSCs) · Healthy Food · Public Procurement · Schools · Swot analysis

1 Introduction

In recent decades, school food policy has been framed as a health intervention designed to combat rising rates of overweight and obesity [1, 2]. In this way, school meal systems can be seen as levers to enable large-scale food sustainability transitions. In Portugal,

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the transposition of Decree-Law n.º 111-B / 2017 of August into the Public Procurement Code (CCP) (Decree-Law n.º 18/2008, de 29 de Janeiro[1]) has created opportunities for different local, municipal and national institutions to transform the public procurement of schools. The portuguese governance model of public canteens includes the possibility to decentralize the management to other public or social economy entities (i.e., municipalities, parishes, Direção-Geral dos Estabelecimentos Escolares - DGEstE).

Procurement schemes should promote food and nutrition appropriate to the specificities of each territorial context, considering proximity schemes (i.e. family farms, local and seasonal production, SFSCs and various types of certified quality schemes, e.g. organic production - Law no. 34/2019, Official Gazette no. 98/, 2019[2]) [3]. In this process, municipalities have been identified as strategic stakeholders [4] to promote new business models supporting local farmers and provide more nutritional and healthy foods to schools.

This paper is divided into five sections, following this introduction of the general context of the research and objectives. Then, we will present: a literature review on SFSC classification approaches; a methodology section illustrating the results of a qualitative survey founded on interviews; results and discussion sections; and a conclusions section and future research steps.

1.1 Short Food Supply Chains

The EU's rural development regulation (1305/2013[3]) defines a "short supply chain" as a supply chain involving a limited number of economic operators, committed to cooperation, local economic development, and close geographical and social relations between food producers, processors and consumers. The actual meaning of SFSC differs across various social groups, institutional settings and regional contexts. It involves certain characteristics of SFSCs and values associated to them. In general, SFSCs are perceived as re-establishing authenticity in production and consumption [5, 6]. Furthermore, local food policy usually views "food from somewhere" [7]. Not as a commodity market or a commercial service, but as an investment in the health and welfare of the citizens of tomorrow.

SFSC idea is more narrowly focused and takes into account the relationships among the many players that are directly engaged in the creation, processing, distribution, and consumption of novel food products [8]. Charatsari et al. [9] defined SFSCs as food production and distribution channels, where the number of agents or actors that mediate between the producer and the final consumer of a product is minimal or zero, and

[1] Decree-Law n.º 18/2008, de 29 de janeiro. Diário da República n.º 20/2008, Série I de 2008–01-29, páginas 753 – 852. Retyrieved from https://diariodarepublica.pt/dr/detalhe/decreto-lei/18-2008-248178.

[2] Law nº 34/2019, de 22 de maio. Diário da República n.º 98/2019, Série I de 2019–05-22, páginas 2544 – 2546. Retrieved from https://diariodarepublica.pt/dr/detalhe/lei/34-2019-122373681.

[3] Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005. Retrieved from https://eur-lex.europa.eu/eli/reg/2013/1305/oj.

where their structure permits the seamless, two-way flow of information between the endpoints of the chain. Such systems have the potential to redistribute power in the agri-food sector, promote cooperation within rural communities by bringing producers and consumers closer together, and mitigate the negative environmental effects of globalized food distribution networks, despite critical debate on the capacity of local food systems to curb the energy and pollution costs associated with the transportation of food (i.e. "food miles") [10]. Therefore, the purpose of SFSCs is to effectively establish localized direct relationships between producers and consumers, separating them from the intermediary actors and constructs that make up globalized food supply chains. In a nutshell, the ultimate goal is to enhance the efficiency of the networks that support agriculture and food provision.

Four different types of supply networks can be classified according to either geographical proximity (i.e. physical distance) or organisational proximity (i.e. the way actors belong to the same relational account or social network): supply chains with loose ties; indirect relationships; long-distance relationships; and direct relationships [9]. The last three correspond to short supply chains, while the first is comparable to globalized food supply chains.

In order to understand the supply networks in Alto Minho and improve the implementation of Short Food Supply Chains (SFSCs) to schools's canteens, this study aims i) to map stakeholders engaged in the regional food supply chain, ii) to identify barriers to reduce the distances between farmers and school consumers, from the perspective of production side iii) to identify facilitators from the production side, iv) to identify barriers from the perspective of the consumers (Municipalities/School Groups/Non-Grouped Schools), v) to identify facilitators from the perspective of consumers.

To understand the different dynamics and networks, we adopt an interdisciplinary vision crossing sociological, geographical and economical approaches. This methodological proposal helps to better analyse the barriers and facilitators enabling the development of SFSCs.

2 Research Methodology

2.1 Study Case

Alto Minho is located in the north-west of Portugal, in the traditional province of Minho, comprising the municipalities of Arcos de Valdevez, Caminha, Melgaço, Monção, Paredes de Coura, Ponte da Barca, Ponte do Lima, Valença, Viana do Castelo and Vila Nova de Cerveira, with a population of around 250,000 inhabitants spread over an area of 2210 km^2.

In Alto Minho there are 114 pre-schools, 85 primary schools, 26 secondary schools, 33 secondary schools and 32 secondary schools. A total of 31,960 students are enrolled in pre-school, primary and secondary education. There are also eight higher education colleges of the Polytechnic Institute of Viana do Castelo, with colleges in the areas of management, technology, health, education, agriculture, science and sport, totalling 4,228 students. A considerable number of meals are served each month in school canteens, which depending on the municipality can be managed directly, under concession or mixed management. The entities responsible for managing school canteens can be the local authority, the Ministry of Education, the school or parents' associations.

Agricultural activities with a higher level of specialization, such as viticulture, beef production and horticulture, as well as organic production methods, contribute greatly to regional agricultural production. There is also a significant number of families who use agriculture as a means of subsistence, to supplement their income and occupation, rather than as a professional activity. Extensive meat production is mainly located in the mountain areas, particularly in the municipality of Arcos de Valdevez, vineyards in the hillside and valley areas, mainly in the municipalities of Ponte de Lima and Viana do Castelo, and milk, vegetables and flowers in the valley areas near the coast or close to the Minho and Lima rivers.

2.2 Methods

We conducted twelve semi-structured interviews with the different actors and stakeholders in public food procurement in Alto Minho. The interviews were held in four municipalities (Ponte de Lima, Arcos de Valdevez, Valença and Caminha) in October 2023. The main goal was to understand their role in the SFSCs and identify the main barriers and facilitators to the implementation of SFSCs to schools. The actors involved were: farmers who supply school canteens, kitchen/canteen managers of each typology of consumers ((Municipalities/School Groups/Non-Grouped Schools), public procurement managers in each type of management (municipalities, parishes, Direção-Geral dos Estabelecimentos Escolares – DGEstE), the mayor of each municipality and managers of/School groups/Non-Grouped Schools. The bilateral interviews and multi-actor interviews were fundamental in establishing effective and productive relationships to enable a shared understanding of goals or a shared commitment to change and to ensure that municipalities and producers concerns and aspirations are understood and considered. The interviews applied address the six main components of the food system: production; processing; distribution; retail; catering and waste. It investigates the supply of basic food products; the use of land for current and potential food production; and the current food supply capacity of the surrounding region in relation to Alto Minho's food needs. It also investigates which businesses are involved in the preparation, distribution, sale, recycling or disposal of food in the city region and the city itself.

3 Results

The following Tables 1 and 2 gives a summary of barriers on the production side and on the perspective of Municipalities/School groups/Non-grouped Schools

The following Tables 3 and 4 gives a summary of facilitators on the production side and on the perspective of Municipalities/School groups/Non-grouped Schools

We carried out a deeper analysis of the content of the interviews in each of the municipalities (see Table 5), identifying strengths, weaknesses, opportunities and threats which will allow us to draw up a strategy and develop medium and long-term policies, which leverage the territory and produce a more positive and innovative change in the Food System.

Table 1. Barriers on the production side

Imbalance between food production and demand (volume, variety and seasonality), namely due to: • Low awareness of local production and seasonality among consumers, authorities and local bodies; • Food consumption habits that are not compatible with the supply of local produce; • Menus not suited to local production; • Low competitiveness compared to other players in the supply chain (eg. Big catering firms), namely: • Lack of capital for investment • Lack of time and manpower
Logistical and organizational difficulties in getting production out the door and distributing it, with response times out of step with demand
Limitations arising from the rules for public procurement, affected by producers' lack of knowledge or difficulty in mastering the procedures and bureaucracy required to respond to tenders

Table 2. Barriers on the consumer side

Public management models comply with public procurement requirements that are too complex for small logistics operators such as small farms
Aggressive competition from other larger food distributors who are better established in the market: • Distrust of local producers for this type of marketing; • Dealing with resistance/inertia from local canteen managers (making, ordering and contracting); • Lack of commitment from local producers to supply on a regular basis and with consistent quality
Logistical infrastructure: packaging, storage, order management, transportation
Difficulty in identifying local producers susceptible to respond to public procurement requirements

4 Theoretical and Practical Implications

The results presented in this study have theoretical and practical implications. Small producers have many constraints related to complex regulations and logistical support. Also, experienced great problems in meeting requirements for public procurement procedures. They expressed that there has not been enough support from governments. These findings are in line with other recent studies [11]. Despite the barriers identified, our findings suggest that Alto Minho stakeholders' network have a lot of potential to assure SFSCs to provide food to schools, but SFSCs could be instrumental to policies addressed to support/reward virtuous practices of food production-distribution-consumption (e.g. low input/low carbon emission/low energy consumption methods of production; use of

Table 3. Facilitators on the production side

Existence of European and national legislation that promotes the consumption of local products and the good use of public funds. Such as: • Farm to Fork strategy (EU); • PEPAC (EU); • SDG Agenda 2030 (EU); • Paris Agreement (carbon neutrality); • Action Plan for the Circular Economy in Portugal; • National Strategy for Green Public Procurement (ENCPE 2020); • National Strategy for Food Security and Nutrition (ENSANP); • Transfer of competencies in local government; • Amendment of the Public Procurement Code to allow direct of foodstuffs

Table 4. Facilitators on the consumer side

The existence of Law no. 34/2019 and the amendment to the CCP allow canteens to be supplied with local products; Alternative food supply that does not compete with large supply companies; The fact that only a few canteens take part in this type of supply makes it possible: • Start with a few producers and increase supply on a regular basis, scaling up to involve a larger number; • Start with little production and no special infrastructure needs; Greater awareness and alertness to these initiatives will boost coordination between local entities so that this work can be carried out

recyclable packaging; optimization of transport, etc.). SFSCs can create business opportunities especially for SMEs. They can be taken into consideration as complimentary to product innovation, for example in the case of the use of local breeds and varieties and of on farm processed products. They are a key to differentiation strategies aimed at creating market niches and getting a premium price. In fact, one of the most relevant limitations of globalized food chains is their size, in general too big to host small quantities, high quality products. In the past this limitation prevented farmers to innovate and quality standards were defined by retailers or processors giving the way to standardization. SFSCs provide market access to fresh and seasonal food produced in peri-urban farm areas, addressing issues such as food sustainability, healthy nutrition.

5 Conclusions, Contributions and Research Agenda

This study identifies the main needs or instruments required to implement short food supply chains to supply schools. Despite our results, it is important to do a reflection about the determinants of SFSCs effectiveness, taking into account the multiplicity of aspects involved.

Table 5. SWOT Analysis

Strengths	Weaknesses
Offer of high-quality traditional food products Healthier and fresh food products Established trust with consumers Geographical and organizational proximity between producers and consumers Presence of the cooperatives - Innovative forms of partnerships and collaboration	Insufficient knowledge and resources to apply for funds Lack of internal expertise regarding regulations Low level of marketing skills, limited resources Lack of own infrastructure Weak negotiating position against food processors, traders, wholesalers, and large retail chains Insufficient logistics and distributions network
Opportunities	**Threats**
Demand for organic food products continues for grow Growing focus of consumers' on welfare and health, but also to environmental sustainability Consumers trust in local farmers Improve Internet as a marketplace for agricultural products The offering of an attractive alternative with niche products to trend of globalization	Complex regulations that are difficult to understand by small producers High level of bureaucracy There is no right adaptation of EU regulations for SFSC markets and small farmers Insufficient logistical support to SFSCs by public organizations Taxation rates not adjusted to small farmers

We conclude that SFSCs present a set of social, cultural and economic benefits [12], with enormous potential for the development of the territory and preservation of the environment [13]. SFSCs have advantages in terms of environmental sustainability when we refer, for example, to the use of fossil fuels or minimizing the use of packaging, or when there is the adoption of pesticides and less intensive production methods [14]. The impact of the entire chain must be considered, from production methods, processing, packaging, distribution, refrigeration, transport and waste management. Beyond the environmental and sustainable aspects of SFSCs, this study also allows us to identify economic, social and legal aspects. SFSCs can potentially reconfigure peri-urban landscapes, revitalizing multifunctional agriculture, providing new opportunities in rural areas and boosting the creation of new jobs [14, 15].

SFSCs provide space for community member interactions thus strengthening their social capital in terms of networks, inclusion, knowledge and social cohesion. SFSCs can contribute to revitalise local economies [16]. However, accessibility is essential to increase the use of SFSC as an alternative purchasing channel. To achieve this, it is necessary to facilitate farmer involvement, more innovative cooperation and coordination between farmers, municipalities and the scientific community through, for example, the creation of food innovation centers. The reinforcement of regional and local public campaigns is needed too. Seems an excellent way of informing citizens about the benefits provided by SFSCs, increasing the awareness of local actors and thus helping to improving consumer confidence.

From the municipalities perspective they recognize the need to value small-scale agriculture and promote the local economy, but they assume that there is an urgent need for a legal framework favorable to the development of a locally based agri-food strategy aiming at the development of the short agri-food supply chains, and with the active role of the regional administration and associative organizations for its creation and promotion. Our results will help to unlock the potential for competitiveness and sustainability by stimulating practical innovative solutions to problems in the short food supply chain domain at local and regional levels. Producers face logistical and organizational difficulties and have several limitations, like lack of knowledge or difficulty in mastering the procedures and bureaucracy. Globally, it is evident that an innovation deficit exists in short food supply chains, but the main constraining factor is the lack of capitalization of knowledge between the various stakeholders in the regiona/local food system. on them. Future research could explore the effects of regional customs and culture on motivations, social relations, governance and expand the scope of research to other regions.

Analysis across countries in different socioeconomic and cultural contexts could also provide insights into how the characteristics of SFSCs models change in different contexts.

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Willingness to Pay for Ecolabel in Food Products: Mapping Publications Over the Past Twenty years

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Abstract. Ecolabels can be a tool to promote and support more sustainable products, providing information that allows consumers to select products with better environmental performance. Ecolabels can help create ecological awareness around sustainable consumption, promote environmentally friendly attitudes, and contribute to responsible consumption habits. This article reviews the literature on willingness to pay for ecolabels on food products and identifies four main knowledge gaps: (1) the effect of variables that signal quality, safety, or health benefits on willingness to pay for ecolabels; (2) the impact of ecolabels on the environment from a regulatory point of view; (3) the lack of a measurement instrument that serves general application with various stakeholders; and (4) how ecolabels contribute to green innovation. Our results contribute to the literature and define and implement more efficient and effective public policies that facilitate communication between producers and consumers. Based on 31 articles selected and analyzed in a systematic literature review, we found that the variables related to consumers' willingness to pay vary according to the level of education, income, age, marital status, family size, attitude, previous experience and knowledge, among others. We conclude that consumers are willing to pay more for environmentally sustainable products and that the ecolabel is particularly important in their choice.

Keywords: Willingness to pay · ecolabel (s) · Food Products · Clusters

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1 Introduction

Ecolabels are important informational cues that provide information on the environmental impacts of products. They act as important sources of information for environmentally concerned consumers during their purchase decision-making process and offer assurance [1].

Ecolabels are a privileged tool for communicating with the consumer and, therefore, they are given particular emphasis in research on two complementary aspects: i) the role they play in consumer decision and which attributes they value most, and ii) quantifying the premium that consumers are willing to pay for eco-labeled food products. Trust in the food industry is essential for consumers as it directly impacts our health and well-being. However, in recent years, there have been several scandals that have eroded this trust. From tainted food products to misleading labeling and advertising, these scandals have made consumers wary of their food. Consumers are now more cautious about the provenance and safety of their food and are more likely to seek out certified organic products sourced from trusted suppliers [2].

In recent years, bibliometric studies have taken on significant weight in various scientific fields. In the field of ecolabels, the latest bibliometric analyses make it possible to identify thematic groups and emerging trends. They also provide valuable information for researchers, policymakers, and practitioners. On the other hand, they help to identify research gaps for future exploration [17].

This study aims to present a comprehensive overview of current and prospective research into the willingness to pay for ecolabel (s) in food products. To this end, we conducted a systematic literature review employing various bibliometric techniques. To achieve this goal, we we map research trends to gain insights into the state of the field, emergent areas of interest, and potential future directions for research. Thus, within the scope of this article, our central research question is: How willing are consumers to pay for ecolabel (s) in food products?

The article is structured as follows: after the introduction. Section 2 presents the theoretical framework of the topic. Section 3 describes the research methodology used to select the sample of articles on the application of willingness to pay for ecolabels in food products published between 2000 and 2023. Section 4 is an in-depth descriptive analysis of the results. Section 5 analyses the practical implications for management. Finally, Sect. 6 summarizes the main conclusions of the work, proposes a research agenda for future studies, and describes the limitations and main implications of this study.

2 Theoretical Framework

Ecolabels are certifications or labels that indicate a product has met specific environmental standards or criteria. These labels can provide consumers with important information about factors such as resource use, waste production, greenhouse gas emissions, and the overall environmental impact of a product [4, 5]. Using ecolabels, consumers can help drive demand for environmentally responsible products and encourage companies to adopt more sustainable practices [6]. In addition to providing information to consumers, ecolabels can also help companies improve their environmental performance by setting standards and guidelines that must be met for the use of the label [7]. These standards are developed by multi-stakeholder organizations and based on scientific research and best practices [8]. Companies using ecolabels must undergo regular audits to ensure they meet the standards and that the product or service is green [9]. Previous studies suggest that consumers need help understanding what the ecolabels communicate [10, 11]. Ecolabels are also crucial for policymakers because they provide a tool to promote sustainable production and consumption patterns [12]. For example, governments can use ecolabels to support the development of sustainable products and services, encourage companies to adopt more environmentally responsible practices, and increase public awareness of environmental issues [13]. Ecolabels are part of a new trend in ecological policies that emphasize information disclosure to induce environmentally friendly behaviors by both companies and consumers [14]. One of the goals of ecolabels is to reduce information asymmetry between producers and consumers about the environmental attributes of a good [15, 16].

3 Research Methodology

3.1 Method

The articles were selected through two database searches, Web of Science and Scopus, using the keywords "Willingness to pay" and "ecolabel" or "ecolabel", to which we added the following: "Willingness to pay*" and "ecolabel*" or "ecolabel*" to specify the context in question. The search on Web of Science resulted in 290 articles, and on Scopus in 191 articles, for a total of 481 results. A filter was applied considering the time span between 2000 and 2023 and papers published in English only. After this, we reduced the sample to 457 results. Finally, only scientific articles, reviews, and early access articles were selected, excluding other publications such as books, conference proceedings, or so-called grey literature. In the "selection" phase, after eliminating duplicate articles (123 articles), the titles, abstracts, and keywords of the 334 articles were read. Finally, 303 articles were excluded, resulting in a final sample of 31. RStudio software was used according to the PRISMA protocol.

4 Results

4.1 Data Base Information

Carried out this research in 2024, we limited our search to articles published until the last year (2023). The search resulted in a total of 481 articles. We provide a summary of the search results in Table 1.

Table 1 summarizes the information gathered from articles investigating the willingness to pay for ecolabel (s) in food over the last two decades. 334 articles by 852 authors were obtained, with an average of almost 34.09 citations per document. Most papers were co-authored, with an average of 29.94 authors per document. The analysis covers a period of 2 decades, from 2000 to 2023. In the top 10, the more relevant journals are Sustainability (32 articles), Ecological Economics (13 articles), and Food Policy (12

Table 1. Summary of data collected

Description	Results	Description	Results
Main Information about Data		Main Information about Data	
Time Span	2000:2023	AUTHORS	
Sources (Journals, Books, etc.)	155	Authors	852
Documents	334	Authors of single-authored documents	824
Average years from publication	7.1	Authors of multi-authored documents	28
Average citations per document	34.09	AUTHORS COLLABORATION	
DOCUMENT TYPES		International co-authorships %	31
Article	334	Authors per Document	29.94
DOCUMENT CONTENTS		Collaboration Index	3.12
Keywords Plus (ID)	920		
Authors Keywords (DE)	1030		

articles), among others. The journals with the most citations are Journal Clean Production (532 citations), American Journal of Agricultural Economics (490 citations), Food Quality Preference (461 citations), and Food Policy (459 citations).

Analyzing the co-occurrences of the 20 keywords most used by the authors in the final sample of the 31 articles, we obtained 4 clusters of associated words.

4.2 Cluster Analysis

Cluster 1: Willingness to pay for ecolabel (S) in food products

Consumers are willing to pay more for eco-labelled food [1, 17, 18]. Consumers value environmental superiority and, therefore, the higher quality of products identified by certified organic and non-organic labels because of their credibility [17, 19]. Thus, consumers are willing to pay the highest price if food products (strawberries) reduce pesticide use, followed by those produced with reduced impacts on water quality [20]. Also, consumers are willing to pay more for organic and fair trade labels [21]. Communication strategies must be carefully refined to enable consumers to access ecolabel information. Adopting these strategies emphasizes the environmental capacity of ecolabels used in the food industry. Consumers with children maybe willingness to pay more [1]. Demographic variables such as education level, income, age, marital status, family size influence consumers' willingness to pay for eco-labelled food products [20, 22]. Purchasing habits and perception variables significantly affect consumer preference for fresh food (strawberries) produced with environmentally friendly techniques [19]. Previous experience and knowledge significantly influence consumers' willingness to pay for eco-labelled food products [22]. The results show that awareness of action strategies, in our case, recognition and stated understanding of eco-labels, may be a more important predictor of buying eco-labeled seafood. Therefore, consumers' familiarity with the labels needs to increase. Ecolabelling certification of recycled packaging is the central aspect that needs to be improved, followed by government policies, regulations, supply chain innovation, and infrastructure. Consumers incur inconvenience when buying sustainable food products, but prefer recycled packaging material at a standardized price [23]. Barriers to developing and expanding green products were identified: accessibility to more consumers, higher prices, and reduced distribution [24].

Main gap: Effect of variables signaling quality, safety, or health benefits on the willingness to pay for ecolabels.

Cluster 2: The influence of ecolabels on consumer behavior

In eco-labelled food products, knowledge and the experience of buying these products, among other variables, clearly differentiate consumer groups [25]. The information and knowledge surrounding eco-labeling are relevant to the positioning of these products in consumers' minds when they make a purchasing decision [26–28]. Increased interest in buying sustainable products can occur if the benefits and tangible impacts on the environment are promoted. Increased demand can lower the price standards of sustainable products to compete with traditional products [23]. Ecolabels provides a wide range of indicators regarding willingness to pay compared to other labels, and preferences for the local label are not affected by the appearance of additional information labels on the same product. The value of the product label is linked to the consumer's perception of the seller and choice of supplier [29]. It is necessary to spread altruistic values among consumers, encouraging pro-social and pro-environmental behavior, reducing inhibiting factors such as pluralistic ignorance, and increasing consumer knowledge, skills, and confidence [30].

Main Gap: Lack of contributions on ecolabels that provide the bridge between ecosystem construction and economic development (green innovation)

Cluster 3: Ecolabels' contribution to the environment

Western eating habits consume many resources and are detrimental to the climate. Changing consumption patterns towards more sustainable consumption seems to be a critical goal for a sustainable future [24]. Recently, some food companies have developed labeling systems to help inform their consumers about the impact a particular food product has on the environment during its production [31]. In the case of seafood, positive attitudes towards the marine environment and sustainability are associated with the increased purchases of eco-labeled products. Lack of understanding of ecolabels, limited information about product sustainability, and lack of in-store guidance have been identified as the main barriers to buying eco-labelled seafood [11]. Although consumers have positive attitudes towards the sustainability attributes of food products, constraints still prevent their purchase behavior from being realized [24]. The healthy properties of eco-labelled food, as well as the communication of knowledge about climate change, significantly affect the level of organic food consumption [2]. Consumers who reported concerns about the environmental impacts of tuna production are less likely to consume the product than other consumers [32].

Main Gap: Impact of ecolabels on the environment from a regulatory point of view.

Cluster 4: The relationship between ecolabels and certification policies

Food products incorporate a significant fraction of the emissions released into the environment [28]. A private labeling program for food products could help bridge the policy gap by encouraging companies to identify efficiencies throughout the supply chain and consumers (by influencing their choices) [33].

Consumers need to be made aware of the differences between different labels. A simple and straightforward recommendation for the agri-food industry, regulators, and manufacturing policy should involve communicating better with consumers through collaborative campaigns on schemes and certifications [34]. Too many food product sustainability labeling schemes confuse consumers [35]. So, it will be useful to start a process of knowledge and evaluation of the benefits of the quality mark in the territory of origin of the PDO food product [36].

Main gap: Measurement instrument that serves general application with various stakeholders.

5 Theoretical and Managerial Implications

This study holds substantial significance for the literature by highlighting the relevance of the ecolabel (s) in food products. It accomplishes this by identifying previously investigated issues, their respective contributions, and primary conclusions. In doing so, it offers a comprehensive map of the literature, providing insight into the main themes discussed, key findings, areas of uncertainty, and avenues for future research. The findings highlight significant prior research in this domain, comprising a total of 31 articles clustered into 4 categories: 1) Willingness to pay for ecolabel (s) in food products, 2) The influence of ecolabels on consumer behavior, 3) Ecolabels' contribution to the environment, and 4) The relationship between ecolabels and certification policies. Additionally, the study offers considerable managerial implications.

Cluster 1: Firms need to know the WTP for its products and those of its competitors. Managers can use WTP measures to choose pricing policies and the optimal research design in a specific context.

Cluster 2: Ecolabels can be Effective Marketing Tools; the ecolabel is perceived as an essential guarantee for the purchasing choice by providing reliable information: consequently, this tool can be used in marketing strategies to prevent vague and misleading assertions and attract those target consumers whose choice depends on variables such as trust and reliability of the producer. Policymakers can use the information from our study to motivate their efforts to support precise and reliable ecolabels that can provide consumers with credible and verifiable environmental details. In fact, without practical policy actions that are indeed able to support the development of the most reliable ecolabeling initiatives, the strong environmental 'push' from consumers will probably have a limited impact on the market.

Cluster 3: Retailers have great potential in promoting ecolabels at their points of sale, in educating customers to understand, recognize, and accept ecolabels, and finally, in adopting Green consumption.

Cluster 4: Common guidelines on environmental claims are needed at the European Union level to improve the use of ecolabels as marketing and information tools.

6 Conclusions, Contributions and Research Agenda

Ecolabelling is a tool to promote and support more sustainable products by providing information allowing consumers to select products with better environmental performance. In this sense, ecolabels can help create social awareness around sustainable consumption and promote environmentally friendly attitudes, creating responsible consumption habits among consumers [26]. It has also been found that consumers are willing to pay more for environmentally sustainable products [18].

Briefly, the variables that define consumers' willingness to pay include the utility of the good or service, as the perceived utility of the consumer is an essential factor in determining their WTP (if a good or service is very useful or desired, the consumer will be willing to pay more for it); the consumer's income, as it influences their ability to pay for goods and services (the higher the income, the higher the WTP) the replacement price, in case there are similar alternatives available in the market at lower prices (in these cases the WTP will be lower); and the perception of quality, as the quality of the good or service also influences WTP if the consumer believes the product is of high quality, consumers will be willing to pay more for it. WTP combines these and other variables and can vary according to consumer circumstances and preferences. The bibliometric analysis of the willingness to pay for ecolabels revealed four distinct groups, each representing a specific area of knowledge. In particular, the literature relating to the first group, "willingness to pay for ecolabel (s)," and the second group, "The influence of ecolabels on consumer behavior," appear to be more advanced in terms of scientific contributions compared to the other groups. There is considerable potential for advancing knowledge about "Ecolabels' contribution to the environment" and the group "The relationship between ecolabels and certification policies". When analyzing cluster 4, few authors focus on this subject, opening up space for a more in-depth analysis. Ecolabel certification policies require concerted action between producers, consumers, and the industry. The primary constraints of this study revolve around the utilization of solely the Web of Science and Scopus databases, as well as applying specific filters such as timeframes, restricted categories, and the exclusion of non-empirical sources like books, dissertations, theses, presentations, and working documents. The search criteria employed involved articles containing specific terms like "Willingness to pay", "eco-label" or "ecolabel", appended with "*". While this method was comprehensive, it may have overlooked other relevant articles not explicitly categorized under these terms. This study offers significant contributions to the advancement of the literature. Initially, we carried out a systematic review of the willingness to pay for ecolabels on food products using bibliometric techniques. Our review not only reveals the current state of the literature but also lays the foundation for subsequent research. It summarizes the main gaps in the understanding of this subject, providing clues for future studies and outlining potential directions for research in this field.

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Ready-to-Eat Sterilised Vegan Meals Incorporating the Seaweed *Porphyra sp.*

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Abstract. The growth of the world's population has led to an increase in food production and the search for more sustainable food solutions that meet people's nutritional needs. The search for complementary and/or alternative protein sources, with a view to reducing consumption of animal proteins, is one solution to achieving a more sustainable food supply chain. This is where seaweed come in, as they are nutritious and sustainable, do not require arable land, are able to grow with few nutrients and are versatile in terms of their use in various industries, including food.

Two nutritionally balanced ready-to-eat (RTE) vegan meals incorporating the seaweed *Porphyra sp* were prepared and sterilised: chickpeas and tofu salad with *Porphyra sp.* seaweed and vegetarian chilli with *Porphyra sp.* seaweed and brown rice. The nutritional composition of the meals was studied using the nutritional information available on the suppliers' technical sheets and FOOD PROCESSOR® software The vegan meals Nutri-Score and Carbon Footprint were calculated. The hedonic tests were carried out using the 7-point Hedonic Scale, evaluating five parameters (aroma, colour, flavour, texture and overall acceptability) and using an untrained panel of tasters made up of 104 participants. The intention to purchase the meals was also analyzed.

This study demonstrates that vegan RTE meals with seaweed can be nutritionally balanced and a good source of proteins. They have a low carbon footprint and are acceptable from a hedonic perspective. These meals are microbiologically stable and do not require energy consumption for their preservation.

Keywords: ready-to-eat vegan meals · seaweed · sterilisation

1 Introduction

Nowadays, consumers are increasingly demanding in their choices and, due to changes in eating, social and cultural habits, they tend to buy more convenient foods with attractive organoleptic characteristics that are nutritionally balanced, beneficial to health and

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microbiologically safe [1]. The growth of the world's population means an increase in food production and, at the same time, a search for more sustainable food solutions that meet people's nutritional needs. The search for complementary and/or alternative protein sources presents itself as a solution to achieve a more sustainable food supply chain. This is where seaweed come in, as they are nutritious and sustainable, do not require arable land, are able to grow with few nutrients and are versatile in terms of their use by the food industry. The introduction of seaweed into the diet aims to add nutritional value to the ready-to-eat meals made available by supply chains [2–4]. The scientific debate on the concept of sustainable diets has been increasingly on the agenda and, according to the Food and Agriculture Organisation of the United Nations (FAO), sustainable diets are defined as "nutritionally adequate and healthy, safe, with low environmental impact, economically fair, accessible and culturally acceptable" [5]. Considering climate change as one of the many environmental concerns, greenhouse gases from livestock farming account for 14.5 per cent of global emissions. Many strategies to curb climate change have been adopted, such as improving efficiency, various technological advances or reducing food waste, but it has been shown that they are insufficient to reduce greenhouse gas emissions, so diets will have to be changed, particularly regarding meat consumption, which will have to decrease [4]. Thus, consciously, or unconsciously, there is now an increase in adherence to "plant-based diets", which include vegetarianism, veganism, or flexitarianism. The basis of these diets presupposes the main consumption of plant derivatives but may include small quantities of animal-origin foods. Thus, this adherence has driven advances in the food industry with plant-based alternatives to animal products, but with a similar flavour, texture, or taste to those of animal origin [5, 6]. There may be several reasons for this growing shift towards plant-based diets, but among them the following stand out: environmental factors (animal production is strongly criticised for its negative environmental impacts), greenhouse gas emissions, landscape degradation or excessive use of water resources. Or even nutritional factors, because according to the literature, plant-based diets tend to be associated with higher dietary quality and a lower risk of chronic diseases [5, 7–9]. Based on various studies, it is estimated that products from the land could saturate the soil in the long term and that new food sources are needed. Seaweed are an alternative that has been gaining prominence, as they are nutritious and sustainable, do not require arable land, can grow with few nutrients and are versatile in terms of their use in various industries. Seaweed are nutritionally rich in minerals (iron, calcium, iodine, selenium, potassium, magnesium) and vitamins (A, B1, B2, B6, B12, C and E), as well as being sources of omega-3, soluble dietary fibre and some of them are rich in protein. It should be noted that they are one of the few plant sources of vitamin B12. In terms of their benefits for human health, they have anti-inflammatory, antiviral, anti-tumour, anti-diabetic, antibacterial, anti-fungal, prebiotic and antioxidant properties [2, 3, 5–8, 10–12]. In terms of iodine, brown seaweed are the richest in this mineral compared to green or red seaweed (e.g. *Porphyra sp.*), so the recommended dry intake is 3 to 5 g, which corresponds to the daily dietary allowance (RDA) of 100–150 μg [13]. In addition to these nutritional characteristics, seaweed are generally fast-growing and do not require fertilisers or saturate the soil, making them an environmentally sustainable option for more frequent inclusion in the diet [5, 7]. Therefore, due to the increased demand for seaweed, their sustainable production in aquacultures has increased, guaranteeing high-quality food for the growing population [11]. The similarity between the taste of seaweed and fish could be a point in favour of their consumption among fish eaters, as it gives consumers a sense of familiarity, tending to reduce potential neophobia [8–10]. One of the concerns of plant-based diets is the source of protein, which is acquired from legumes, seeds, cereals or mycoproteins. It is therefore considered an advantage to combine various ingredients to improve the composition of the product in terms of nutrition, technology, function, and consumer preferences [5, 7, 8].What's more, consumers are increasingly looking for pre-cooked meals with attractive organoleptic characteristics that are nutritionally balanced, beneficial to health and microbiologically safe, thus allowing them to save time when shopping for and cooking their meals, given the hectic lifestyle that society imposes and the consequent change in eating, social and cultural habits. On the other hand, households tend to be smaller, leisure and the importance of free time have increased and the tradition of family meals at the base of the Mediterranean Pyramid has been lost over time [14]. The aim of this article is to report on a study into the development of new ready-to-eat, pre-cooked and sterilised vegan meals incorporating the seaweed *Porphyra sp*, which are intended to meet the needs of the market in terms of offering healthy, sustainable, and practical (for those who don't have time to cook).

2 Materials and Methods

2.1 Recipes and Meal Production

After several preliminary tests was possible to develop 2 meals with seaweed *Porphyra sp.*: (Table 1) Chickpea and tofu salad and (Table 2) Vegan chilli with brown rice.

Zucchini, tomato, black olives, coriander, garlic, sweet corn, carrots and green pepper were purchased from IFT Gelcampo (Portugal). Seaweed (Nori, *Porphyra sp.*) was purchased dehydrated from producer Algas Atlânticas, Algamar, S.L. (Pontevedra, Spain) and was hydrated before use (about 10% dry seaweed in water). Natural organic tofu and soybean were purchased from Biodharma (Portugal). Soybeans were hydrated overnight before use. Natural cashews were purchased from Zenalco - Auchan Retail (Spain). Chickpeas (canned) and red beans (canned) were purchased from a local producer Raimundo e Maia (Portugal) and drained before use. Tomato puree was purchased from Sugal (Portugal). Extra virgin olive oil was purchased from local producer (Gallo Worldwide, Portugal). Salt was purchased from Salexpor (Portugal). Brown rice (ready-to-eat, pasteurized) was provided by Ernesto Morgado S.A. (Portugal). Pepper, garam, chilli pepper, xanthan gum and oregano were purchased at a local market.

All ingredients were weighted on a scale. In the chickpea and tofu salad, a homogeneous mixture was made with the natural cashews, olive oil, salt and pepper, by using a blender, and then mixed with the remaining ingredients. In the chilli recipe, the onion, garlic, and olive oil were previously sautéed before the addition of the remaining ingredients (except for the hydrated seaweed, oregano, coriander, and xanthan gum) for cooking. After turning off the electric stove, the missing ingredients were added.

After several experimental formulations, two final formulations were realised. All the equipment and utensils used in the food handling area were made of materials that did not transmit toxic substances, odour, or taste, were non-absorbent, resistant to corrosion and recurrent disinfection [15].

Three hundred grams of grain and tofu salad, two hundred grams of chilli, one hundred grams of brown rice were weighed into the respective containers and went through the sterilisation cycle.

Table 1. Formulation A "Cold chickpea and tofu salad with *Porphyra sp.* seaweed (per portion)"

Ingredients	**Weight (g)**
Natural organic tofu	59
Chickpeas	70
Hydrated seaweed (*Porphyra sp.)*	21.6
Zucchini	19
Tomato	24
Black olives	23
Coriander	2.3
Garlic	7
Natural cashews	59
Extra virgin olive oil	14
Salt	1.9
Pepper	0.05
Total meal	**300**

2.2 Sterilisation Packaging and the Sterilisation Process

Each product was packaged in different packaging, but both were suitable for the sterilisation process. The film of both packages is composed of 3 layers: biaxially oriented polyester and coated with a SiOx film, biaxially oriented polyamide film and laminated and co-structured polypropylene film. These Koro-Top® films are suitable for sterilisation at 125ºC and suitable for use for up to 24 months, counting from the date of production, maintaining correct storage conditions. Product A was packaged in cups with a thickness of 1.3mm, made of polypropylene (PP)/5% Ethylene Vinyl Alcohol Copolymers (EVOH)/PP, black in colour and Product B was packaged in white cups, with the same composition, simply thicker (1.9mm). The steriliser used was the Static Steriflow water cascading ® which, in the heating phase, reaches a temperature of 125ºC and pressure of 2.5 Bar, being a sterilisation process that uses water, which is reused in several cycles, resulting in savings. Energy and low operating costs.

Table 2. Formulation B "Vegetarian chilli with *Porphyra sp.* (200g) and brown rice (100g)". (Meal portion = 300g)

Ingredients	Weight (g)
Chilli:	
Extra virgin olive oil	2.9
Onion	20
Garlic	4.3
Tomato puree	26
Red beans	51
Carrots	20
Tomato	29
Sweet corn	20
Soybean, dried	20
Green pepper	8.6
Garam (spices)	0.7
Chilli pepper (spicy)	0.06
Salt	0.9
Hydrated seaweed (*Porphyra sp.*)	13.4
Oregano	0.3
Coriander	0.6
Xanthan gum	0.3
Total ingredients	218
Total (after cooking)	200
Rice:	
Brown rice (cooked)	100
Total meal	**300**

2.3 Nutritional Composition

Nutrition composition of the meals was calculated using the software FOOD Processor®. Seaweed nutritional composition was obtained from supplier (for energy, fats, saturated fats, carbohydrates; sugars, fiber, and salt) and from the literature (for micronutrients: calcium, iron, potassium, iodine, and selenium) [16, 17].

The Nutri-Score was calculated for each meal to evaluate the nutritional profile [18].

2.4 Carbon Foot Print

Regarding sustainability, the Carbon Footprint was studied using the "Food Carbon Footprint calculator" from My Emissions [19].

2.5 Acceptability by Consumers

Sensory analysis of RTE meals was carried for recipes A (Cold chickpea and tofu salad with *Porphyra sp.* seaweed) and B (Vegetarian chilli with seaweed *Porphyra sp.* with brown rice). One hundred and four untrained voluntary adult consumers were invited to participate in a hedonic test. For each test, a 25 g sample portion (designated with three-digit random number codes) was presented. Each portion of product B was placed on a white dish, after having been heated in a microwave (800 W) for 1 min before serving. The serving temperature was approximately 60 ºC. Participants were provided water to rinse their palate upon need [20].

Participants were asked to fill out a questionnaire that comprised:

Product sensory evaluation through acceptability.

1. The acceptability test asked to rate the samples from 1 to 7 (1 = dislike very much, 2 = dislike moderately, 3 = dislike slightly, 4 = neither like nor dislike, 5 = like slightly, 6 = like moderately, and 7 = like extremely) for the following attributes: aroma, flavour, colour, texture, and overall acceptability.
2. Information about willingness to buy the RTE meal (After tasting the product, would you be willing to buy it? no/yes).

3 Results and Discussion

Currently, the convenient nature of RTE meals makes them very popular among consumers, who are switching from homemade food to ready-to-eat products due to workers' busy lifestyles and work schedules. It is estimated that there will be a 4.94% increase in the RTE food market in the period 2024–2029, reaching US$512.74 billion in 2029 [21]. Formulated meals are considered a market trend and in high demand.

3.1 Nutritional Composition

Table 3 reports the nutritional declaration according to Regulation (EC) No 1169/2011 [22]. The energy per 100g was 211 kcal(886kJ) for recipe A and 118 kcal(496kj) for recipe B, which corresponds to 32% and 18% of the daily energy intake for an average adult, respectively considering the serving portion (300g).

According to Regulation (EC) No 1924/2006 both recipes can bear several nutritional claims (Table 4), standing out for their considerable protein content (protein source). It should also be noted that the recipe B has a high fibre content while the recipe A is also a source of iron, iodine, and selenium [23].

The formulated products had a Nutri-Score score of "A" (Table 5) on a scale from A to E (which indicates that consumption of foods with A and B ratings should be encouraged and those with D and E ratings should be limited). These products are recommended from a nutritional point of view, as advocated in the dietary recommendations of the various studies carried out that include the Nutri-Score [24].

Table 3. Nutrition declaration of meals

	A - Cold chickpea and tofu salad with *Porphyra sp.* seaweed		B - Vegetarian chilli with *Porphyra sp.* Seaweed and brown rice	
	Per 100g	**%RI* (per portion**)**	**Per 100g**	**%RI* (per portion**)**
Energy (kJ/kcal)	886/211	32	496 / 118	18
Total fat (g)	15.56	67	3.50	15
Saturated fat (g)	2.52	38	0.50	8
Carbohydrates (g)	13.26	15	17.30	20
Sugars (g)	2.58	9	2.50	8
Protein (g)	7.21	43	5.00	30
Salt (g)	1.00	50	0.60	30
Dietary fiber (g)	2.87	--	3.30	--
Calcium (mg)	51.78	21	36.60	14
Iodine (μg)	28.98	58	17.70	35
Iron (mg)	2.48	53	1.90	40
Potassium (mg)	250.39	38	259.60	39
Selenium (μg)	9.05	49	4.70	26
Sodium (mg)	403.98	--	240.00	--

*RI = reference intake for adults (8400 kJ/ 2000 kcal), according to Regulation (EC) No 1169/2011 [22].
**Portion value = 300g

3.2 Carbon Footprint

The results obtained in this study (Table 6) reflect, a very low carbon footprint of meals. The scale used classifies meals as "A - Very Low Carbon Footprint", on a scale from: A (dark-green - Very Low Carbon Footprint – $<$ 150g CO_2/100g), B (light green - Low Carbon Footprint – 150-250g CO_2/100g), C (yellow - Mid Carbon Footprint – 250-500g CO_2/100g), D (orange – High Carbon Footprint – 500-800g CO_2/100g), E (red - Very High Carbon Footprint - $>$ 800g CO_2/100g) [24]. The ecological footprint is increasingly a concern for food producers and consumers looking to choose more sustainable products. The products had a reduced carbon footprint as they correspond to a vegan diet, thus corroborating what has been described in various studies that associate a vegan diet with having a lower carbon footprint, due to the absence of animal products [24].

3.3 Consumers Acceptability

Consumers' acceptability represents a crucial aspect in the development of RTE vegan meals. Therefore, we invited a heterogeneous group of possible buyers of RTE products

Table 4. Nutrition claims applicable to the meals. Conformity with the conditions set out in Regulation (EC) No 1924/2006) [23]

Nutrition claim	**Specific conditions**	**A - Chickpea and tofu salad**	**B - AVegan chilli with brown rice**
Source of protein	At least 12% of the energy value of the food is provided by protein	**Yes** (provides 14%)	**Yes** (provides 17%)
Source of fiber	Product contains > 3g fiber/100g	No	**Yes** (contains 3,3g/100g)
Source of iron	Product contains at least 15% of the nutrient reference value per 100g	**Yes** (contains 18%)	No
Source of iodine	Product contains at least 15% of the nutrient reference value per 100g	**Yes** (contains 19%)	No
Source of selenium	Product contains at least 15% of the nutrient reference value per 100g	**Yes** (contains 16%)	No

Table 5. Calculation of Nutri-Score [18]

Recipe	**Score**	**Classification**
A - Cold chickpea and tofu salad with *Porphyra sp*. Seaweed	−1	**A**
B - Vegetarian chilli with *Porphyra sp.* Seaweed and brown rice	−8	**A**

Table 6. Calculation of Carbon footprint [19, 25]

Recipe	**gCO_2e/100g**	**gCO_2e/serving(300g)**	**Carbon Rating**
A - Cold chickpea and tofu salad with Porphyra sp. Seaweed	142	426	A - Very Low
B - Vegetarian chilli with *Porphyra sp.* Seaweed and brown rice	140	420	A - Very Low

to evaluate the acceptability of developed meals. Figure 1 shows meals before plating. Overall acceptability and willingness of purchasing results are reported in Tables 7 and

8. The spider plots (Fig. 2) show how the aroma, colour, flavour, texture, and overall acceptability of recipe A and recipe B are different. Although both recipes had positive results in the hedonic tests and purchase intention, meal B stood out with the highest score.

Table 7. Results of acceptability test of Product A and Product B (mean ± SD)

Product	Aroma	Colour	Flavour	Texture	Overall Acceptability
A	4,41 ± 1,44	4,46 ± 1,20	4,87 ± 1,71	5,04 ± 1,42	**4,94 ± 1,45**
B	5,54 ± 1,25	6,00 ± 0,98	5,72 ± 1,17	5,76 ± 1,07	**5,66 ± 1,07**

Fig. 1. Meals of products A (Cold chickpea and tofu salad with *Porphyra sp.* seaweed) and B (Vegetarian chilli with *Porphyra sp.* seaweed)

Sterilised meals, in addition to being more effective in microbiological control, since sterilisation inactivates pathogenic and spoilage enzymes and microorganisms, preserves the nutritional and organoleptic characteristics of the products [26], their shelf life does not require another type of equipment to remain fit for consumption and its own sterilisation process appears to be more sustainable than other pre-cooked frozen or fresh meals, which in their life cycle will have greater energy consumption [27], as well as a greater safety risk food in a situation where the cold chain could be broken.

Seaweed is a protein alternative to consider, supporting legumes, which, although their production also saturates the soil and uses water resources, could be counterbalanced with the increased use of seaweed and, certainly, are not as harmful to the environment, such as the production of animal protein, which uses greater amounts of water resources and also contributes to greenhouse gases.

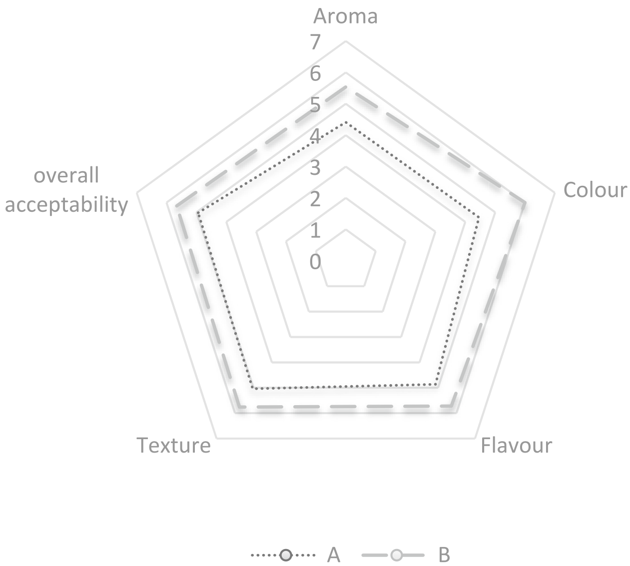

Fig. 2. Results of acceptability test of Product A and Product B

Table 8. Willingness of Purchasing (%) of recipe A and recipe B

	Willingness of Purchasing (%)
Product A	58,7
Product B	79,8

4 Conclusion

The formulations referring to vegan RTE products with potential to be introduced into the market show that it is possible to obtain sterilised meals using sustainable raw materials (legumes, seaweed), with desirable organoleptic characteristics (consumers enjoyed the meals and expressed their intention to purchase), balanced from a nutritional point of view (Nutri-Score A and nutritional claims such as the example "Source of protein"), with a low carbon footprint (A – Very Low) and the packaging does not require refrigeration or freezing, presenting a considerable useful life (12 months).

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Antioxidant and Antimicrobial Properties of Extracts of Wild and Commercialized *Mentha Pulegium L.*

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Abstract. Wild edible plants (WEPs) have always been an essential nutraceutical resource, given their nourishing value in times of food shortage, uses in folk medicine, and ethnographic relevance. Even though their use has declined over time, there has been a growing interest in the recent years for the application of WEPs as they can be an asset to meet the needs for food facing the rapid population growth, global warming, and dietary diversification. Pennyroyal (*Mentha pulegium*) is an endemic aromatic herb that grows wildly in the Mediterranean basin. Aqueous and acetonic extracts of the aerial parts of pennyroyal (wild and commercial) were obtained. Bioactive properties were evaluated in terms of antioxidant capacity (ABTS assay), total phenolic content (Folin-Ciocalteau assay) and antimicrobial activity against Gram-positive (*Bacillus cereus, Bacillus subtilis, Enterococcus faecalis, Staphylococcus aureus*) and Gram-negative bacteria (*Escherichia coli, Klebsiella pneumoniae, Acinetobacter baumanni*). All extracts presented antioxidant capacity, especially the aqueous extracts obtained from wild specimens, due to the presence of phenolic compounds, as proved by the positive correlation (Pearson coefficient 0.89) between the ABTS/TPC assays. Pennyroyal showed antimicrobial activity against *Gram-positive* bacteria.

Keywords: antimicrobial · antioxidant · edible wild plants · pennyroyal

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1 Introduction

Wild edible plants (WEPs) have always been a very important component in the human diet. The term 'wild edible plants', is used for all plants that are found in the wild (open fields, forests, or bushlands), which are considered suitable for human consumption [1, 2]. In ancient times, WEPs were the main source of nutrients, besides hunting [2]. WEPs have been especially important to provide nourishment during food or income scarcity [1, 3], as well as in developing countries, where they are used for different purposes, such as remedies, pigments, poisons, shelter, or fibers [2]. Moreover, in extreme situations (e.g.: war conflicts), WEPs can play a crucial role in people's lives, as those times are usually accompanied by several hurdles, such as shortage of food, water, or medicines, which consequently lead to malnutrition, disease, and death [4].

WEPs are also part of the cultural history of a certain region and contribute to people's local traditions and identity [3, 5]. WEPs play an important role in the Mediterranean diet, with over 100 million people in the EU consuming WEPs, according to the Food and Agriculture Organization (FAO) [5, 6]. In fact, during the last 20 years an increasing number of studies highlighted the strong correlation between the consumption of WEPs and health benefits [7], as they can be a very good source of nutrients, contributing to the satisfaction of dietary needs [3]. Thus, these plants hold a very interesting potential, as they grow in the wild, spontaneously, and under extreme climatic conditions, and less fertile soil, with long exposure to sunlight and water scarcity. WEPs have shown high capacity to adapt to the environment, which translates into less exploitation, more sustainability, and less expenses [2].

Several studies have demonstrated that WEPs can be a good source of nutrients, such as carbohydrates, proteins, and lipids, as well as of bioactive compounds [8–11]. Mediterranean WEPs have shown to present vitamins, minerals, flavonoids, flavonols, proanthocyanidins, vitamin C, tocopherols (vitamin E), carotenoids (vitamin A) and xanthophylls, which can contribute to a better health [2, 5]. Hence, dishes made with WEPs are often identified as functional food [1, 3]. WEPs also have great culinary value given their organoleptic properties and ways of consumption (cooked or raw), to be used as condiments or seasonings, or to prepare beverages, tisanes (herbal teas) and liqueurs. Besides their nutritional value, these plants have been used in local folk medicine as infusions and decoctions, to treat various conditions [2, 3]. WEPs consumption has been associated with diverse health benefits, being effective against certain chronic disorders, such as cancer, cardiovascular diseases, obesity, brain disorders and immune deficiency [5]. Thus, WEPs also hold a strong potential for the pharmaceutical, cosmetics and biotechnology industries [2, 12]. However, WEPs may also contain harmful compounds, namely oxalates, cucurbitacins, pyrrolizidine alkaloids, anthracene derivatives, saponins, phenylpropanoids and prenylflavonoids, being therefore necessary to consume them properly and in adequate amounts.

Pennyroyal (*Mentha pulegium* L.) is an edible aromatic herb of the *Lamiaceae* family found in Portugal, Western, Southern and Central Europe, Asia, Iran, Arab countries, Ethiopia, North Africa, Australia, and North America [13, 14]. Due to its spearmint-like odor and properties, pennyroyal is used in gastronomy, mainly for seasoning, and aromatizing, as well as a natural preservative [13, 14]. Chemically, *M. pulegium* L. presents pulegone, menthone, piperitone, piperitenone and isomenthone, among the major components [13, 14]. *M. pulegium* has several medicinal properties and its dry aerial parts and essential oil are used in traditional medicine for the treatment of various conditions, such as, liver and gallbladder disorders, amenorrhea, gout, colds, bronchitis, sinusitis, tuberculosis, diarrhea, indigestion, flatulence, and vomiting, increased micturition, and skin diseases [13]. However, pennyroyal also presents hepatotoxic and aborticide properties [15, 16]. Moreover, *M. pulegium* has shown great potential as an insect repellent and is commonly applied for that purpose in certain countries [16, 17]. Nonetheless, since it can also be highly toxic, it is prohibited to be included in some products, due to its high content in terpenoids, such as pulegone, present in its essential oil [18]. Pennyroyal has also shown to exhibit antibacterial activity, mainly it's essential oil, particularly against Gram-positive bacteria [19, 20]. *M. pulegium* has also demonstrated to have a significant antioxidant activity [21, 22]. Thus, the aim of this paper was to evaluate the bioactive properties of extracts of *M. pulegium*, namely, their antioxidant capacity and antimicrobial activity against Gram-positive and Gram-negative bacteria.

2 Materials and Methods

2.1 Antioxidant Activity and Phenolic Content

Preparation of extracts. Wild *M. pulegium* was hand-collected in Beja, Alentejo, Portugal, in March 2023, and oven-dried for 3 days at 60 °C. Biologically grown, commercial *M. pulegium* dried aerial parts from *vidaceleiro – INFUSÕES BIO* (batch: 5784; 50 g packaging) were also acquired for comparison. Samples were used to prepare two extracts (aqueous infusions and acetonic extracts). Wild samples (aerial parts, stems, and leaves) were cleansed with distilled water and dried in an oven for 7 days, at 50 ºC, and then macerated. Acetonic extracts were obtained by stirring both samples (wild and commercial dried aerial parts) for 2 h at 300 rpm/min (1 g of sample per 10 mL of acetone 70% v/v) in the dark. In turn, aqueous extracts were obtained by adding 2 g of sample to 50 mL of boiling distilled water and let to stand for 15 min. Extracts were prepared in triplicate.

Total phenolic content (TPC) – Folin-Ciocalteau assay. TPC was measured using a modified Folin-Ciocalteu assay [9, 23]. Aqueous and acetone/acetonic extracts were diluted (1:10) in water/acetone, respectively. Briefly, 0.250 mL of sample and 0.250 mL Folin-Ciocalteu Reagent were mixed, allowed to rest for 2 min at room temperature, followed by the addition of 5.0 mL of sodium carbonate (Scharlau) and 7.0 mL of distilled water. Final solutions were mixed and allowed to react for 1 h in the dark. Absorbances were read at 760 nm by making use of a spectrophotometer (Varian Cary 50 Scan UV-Visible). All determinations were performed in triplicate. Negative controls were performed with the appropriate solvent, using the same method. TPCs were expressed in milligrams of gallic acid equivalents (GAE) per gram of dried extract, by making using of the respective calibration curve ($R^2 = 0.995$) constructed with standard solutions of gallic acid.

Antioxidant capacity - ABTS radical scavenging assay. The antioxidant capacity of *M. pulegium* was assessed by the vitamin C equivalent antioxidant capacity (VCEAC) assay [24], using the ABTS (2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) radical. Briefly, ABTS stock solutions were prepared with potassium persulfate ($K_2S_2O_8$), kept in the dark for 16 h and filtered with a syringe filter (0.45 μm Ø). Before usage, the absorbance of the solution at 734 nm was adjusted to 0.70 ± 0.02 by adding distilled water. Plant aqueous and acetonic extracts were diluted (1:20) in water/acetone, respectively. To evaluate the antioxidant activity, 1.0 mL of diluted ABTS was mixed with 20 μL of plant extract and incubated for 6 min before measuring absorbances (at 734 nm, Varian Cary 50 Scan UV-Visible spectrometer). All determinations were performed in triplicate. The scavenging activity of the ABTS radical was calculated in vitamin C equivalents (VCEAC), per gram of dried extract, by making use of the appropriate calibration curve ($R^2 = 0.998$). The ABTS radical scavenging activity was compared that one of ascorbic acid (Panreac), by calculating the percentage of inhibition:

$$\%inhibition = \frac{A_B - A_E}{A_B} \times 100$$

A_B – initial absorbance of ABTS solution
A_E – radical absorbance after 6 min of reaction with plant extract

Analysis of variance (ANOVA). Differences between extracts, in acetone and water, and samples, of wild and commercial *M. pulegium*, were tested with analysis of variance (one-way ANOVA) based on Tukey's test [25]. All statistical analyses were tested at a 0.05 level of probability using the software STATISTICA.

2.2 Antibacterial Susceptibility Tests

Bacterial Strains. Antibacterial activity tests were performed against Gram-positive and Gram-negative foodborne spoilage and pathogenic bacteria from the American Type Culture Collection (ATCC): *Bacillus cereus* (ATCC 10876), *Bacillus subtilis* (ATCC 6633), *Enterococcus faecalis* (ATCC 29212), *Staphylococcus aureus* (ATCC 6538), *Escherichia coli* (ATCC 25922), *Klebsiella pneumoniae* (ATCC 700603) *and Acinetobacter baumanni* (ATCC 19606). Bacterial strains were inoculated in liquid nutrient broth (NB, Panreac Quimica SA) and grew overnight in an incubator shaker (ABALAB), at 37 ºC.

Disc diffusion method. The antibacterial activity of *M. pulegium* extracts was determined by a modified version of the paper disc diffusion method [26]. Procedures were executed under sterile environment using a laminar flow cabinet (CRUMA 9005-FL). The optical density (OD) of the inoculums was adjusted to 0.125 ± 0.005 at 550 nm, equivalent to the 0.5 McFarland standard. Bacterial suspensions were spread evenly over the surface of the plate (90 mm Ø Petri dishes with Mueller Hinton agar, Thermofisher) by inoculating on four different directions using a sterile swab. After 15 min, filter paper discs (6 mm Ø; Whatman #1) were carefully placed on the agar surface and 10 μL of each extract were loaded into the respective discs. Plates were incubated at 37 ºC, for 16 to 20 h. Water was used as negative control. Ciprofloxacin was used as positive control. Aqueous extracts of wild and commercial pennyroyal were tested at two concentrations (200 mg/mL – AE1 and 100 mg/mL – AE2). Tests was performed in three independent days. Bacterial growth inhibition was determined by measuring the diameter of the inhibition zones (halos) around the discs.

3 Results and Discussion

3.1 Antioxidant Activity

The results obtained from the assays conducted for determining the total phenolic content (TPC) and antioxidant activity (AC) of the aqueous and acetonic extracts of wild and commercialized pennyroyal are presented in Table 1.

Table 1. TPC and ABTS antioxidant capacity of *M. pulegium* extracts (dry weight).

	Samples	TPC (mg GAE/g)	ABTS (mg VCEAC/g)
Acetonic extracts	Commercial pennyroyal	35.38 ± 4.98 a	46.36 ± 0.80 b
	Wild pennyroyal	25.71 ± 7.36 b	30.85 ± 4.02 c
Aqueous extracts	Commercial pennyroyal	35.78 ± 3.25 a	53.48 ± 2.85 a
	Wild pennyroyal	48.63 ± 3.24 a	57.15 ± 2.21 a

Results represent mean ± standard deviation (n = 4).
Means with different letters on the same column are significantly different ($p < 0.05$)

TPCs of pennyroyal extracts ranged from 25.71 ± 7.36 mg g^{-1} for wild pennyroyal acetonic extracts, to 48.63 ± 3.24 mg g^{-1} for wild pennyroyal aqueous extracts. Regarding the antioxidant activity, the VCEAC values ranged from 30.85 ± 4.02 mg g^{-1} for wild pennyroyal acetonic extracts, to 57.15 ± 2.21 mg g^{-1} for wild pennyroyal aqueous extracts. TPCs and VCEACs of the acetonic and aqueous extracts were, in overall, in the range of those described previously [27] for the same species, where the TPC found in *M. pulegium* powder infusion was 20.9 ± 1.43 mg g^{-1}, and the antioxidant capacity measured by the ABTS radical was 19.14 ± 6.16 mg g^{-1}. Thus, the results confirm the positive relationship between the antioxidant potential of *M. pulegium* and its polyphenolic content, as proved by the positive correlation detected (Pearson coefficient 0.89), as seen by other authors [19, 28]. Moreover, the ANOVA analysis (Table 1) applied showed that, regarding the Folin-Ciocalteau assay, there is a significant difference ($p < 0.05$) between the extraction methods for wild pennyroyal. On the other hand, no statistical significant differences were verified between the extraction methods for commercialized pennyroyal extracts, as well as for wild pennyroyal aqueous extracts. Regarding the ABTS assay, significant differences were found between aqueous and acetonic extracts of wild and commercialized pennyroyal.

Both assays (ABTS and Folin-Ciocalteau) detected high VCEAC and TPC in wild pennyroyal aqueous extracts, indicating that hot water is a good extraction solvent for pennyroyal and may be an eco-friendlier alternative to the use of organic solvents. These results corroborate those obtained previously [13, 29] for which hot water extracts of *M. pulegium* presented high antioxidant capacity and phenolic content, when compared to pennyroyal's cold water and ethanolic extracts and essential oils [30, 31].

Besides the solvent used, the plant's development state, as well as the equipment and extraction methodology employed, can influence the content of phenols and the antioxidant capacity obtained for a certain extract. When evaluating the effect of plant storage period on the phenolic content of *M. pulegium* and other plants [32], values varied according to the days of storage. In fact, results have shown that the longest storage period (120 days) presented the lowest TPCs, which can be explained by compound oxidation over time. Although protected from light, air-exposure may lead to the loss of antioxidant properties. This can explain why the hand-collected wild pennyroyal infusion (richer in more hydrophilic polyphenols, such as polyphenolic acids) showed a higher TPC value, when compared to the commercial samples. Commercial pennyroyal is stored packed in a paper bag for long periods [33]. Conversely, acetonic extracts (richer in more hydrophobic polyphenols, such as flavonoids) obtained from commercial pennyroyal showed higher TPC and VCEAC values, indicating that more hydrophobic polyphenols/antioxidants can be preserved for long-term periods.

Additionally, several studies [19, 34, 35] have reported that edaphoclimatic conditions, such as temperature, precipitation, moisture, soil type and composition, as well as altitude, can impact the phenolic content of a plant, and justify the differences found among specimens of the same species.

3.2 Antibacterial Activity

Inhibition halos were measured (mm) for the different samples under study (aqueous extracts and controls of wild and commercial pennyroyal) against the Gram-negative and Gram-positive strains tested. Results are displayed in Table 2. All bacteria, with exception of *A. baumannii,* were susceptible to Ciprofloxacin. Gram-negative strains (*K. pneumonia* and *A. baumannii*) didn't show any susceptibility to any of the extracts, possible due to their more complex double layer outer membrane. In turn, Gram-positive strains (*Bacillus cereus, Enterococcus faecalis, Staphylococcus aureus*) showed minimum susceptibility, with inhibition halos varying between 1.0 and 8.0 mm. Previous authors [13, 19] have also verified that other Gram-positive bacteria (*Bacillus subtilis*, *Brochothrix thermosphacta*, *Clostridium tetani*, *Enterococcus*, *Listeria innocua*, *Listeria monocytogenes* and *Streptococcus aureus*) were also susceptible to hot water and methanolic extracts *M. pulegium.*

Bacillus subtilis, Staphylococcus aureus and *Escherichia coli* were the most susceptible strains at both concentrations tested (AE1 and AE2). In addition, when using other extracting solvents (acetone, ethanol, and methanol), as performed by others, even higher antimicrobial inhibitory effects were obtained [20, 36, 37] that can be attributed to the presence of more hydrophobic compounds, such as terpenoids. Thus, here again, the chemical composition, extraction solvent and extraction method can influence the antimicrobial activity presented by the extracts [38]. Several studies [21, 39, 40], have also ascertained a significant antibacterial activity to *M. pulegium* essential oil (EO). Indeed, [10] a high inhibitory effect of pennyroyal EO was observed against strains of *A. baumannii*, compared to other strains, such as *S. aureus*, *E. faecalis*, *B. cereus*, *E. coli.*

4 Conclusions

In summary, this study demonstrated that extracts (aqueous and acetonic) of the aerial parts of wild European *Mentha pulegium* (pennyroyal) exhibited high antioxidant capacity (VCEAC) and high total phenolic content (TPC), with a positive correlation between

Table 2. Antimicrobial susceptibility against Gram-positive and Gram-negative bacteria. Mean of diameters (mm) of inhibition halos are shown for all tested samples: extracts and controls.

Extracts	*BC*	*BS*	*EF*	*SA*	*EC*	*KP*	*AB*
AE1	2.0	17.0	8.0	2.0	4.0	-	-
AE2	-	14.0	-	2.0	5.0	-	-
Water	-	-	-	-	-	-	-
Ciprofloxacin	9.0	8.7	7.0	3.3	10.3	2.0	-

Gram-positive: *Bacillus cereus* (BC), *Bacillus subtilis* (BS), *Enterococcus faecalis* (EF), *Staphylococcus aureus* (SA); Gram-negative: *Escherichia coli* (EC), *Klebsiella pneumonia* (KP), *Acinetobacter baumannii* (AB), Aqueous extract 200 mg/mL (AE1), Aqueous extract 100 mg/mL (AE2).

detection methods (ABTS radical scavenging assay and Folin-Ciocalteau assay). Aqueous/infusions extracts were able to extract more polyphenolic and antioxidant compounds than acetonic extracts, especially from wild pennyroyal, proofing that water can be a suitable and eco-friendly extraction solvent of bioactive compounds of *M. pulegium*, also stating that aromatic herbs should be preferably used in their fresh forms (instead of using samples stored for extended periods). Additionally, aqueous extracts also showed antimicrobial activity, especially against Gram-positive bacteria such as *B. cereus, B. subtilis, E. faecalis, and S. aureus*. Hence, due to *M. pulegium* antioxidant and antimicrobial properties, further studies should be conducted to evaluate and propose strategies to safely use this plant in the agri-food, biotechnological, cosmetic, and pharmaceutical sectors.

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Future-Proof a Mediterranean Soup

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Abstract. The Mediterranean diet (MD), known for its global popularity, emphasizes fresh, high-quality plant-based foods. It is associated with a reduced risk of several noncommunicable diseases (NCDs). This diet also promotes sustainability by encouraging the consumption of seasonal produce and reducing food waste. A key feature of the Mediterranean diet is its reliance on soups (vegetable and legume based), easy to prepare, nutrient-rich and highly affordable. Soups also contribute to sustainability by utilizing agricultural by-products and reducing food waste. The consumption of soups, especially when part of the Mediterranean diet, offers numerous health benefits. These include antimicrobial, anti-inflammatory, and antioxidant properties, which can help manage certain health conditions in a sustainable manner. In this work, a bibliographical review will be carried out on this topic in order to highlight the importance of consuming soups related to the Mediterranean diet for human health and food sustainability. In this way, we hope to increase readers' food literacy.

Keywords: Mediterranean Diet · Food Sustainability · Soup · Health

1 Mediterranean Diet and Sustainability

The Mediterranean Diet (MD) is a dietary pattern that has been widely recognized for its health and quality-of-life benefits [1, 2]. It was first studied in the mid-20th century by Ancel Keys, who observed that Mediterranean populations had lower rates of cardiovascular disease and longer life expectancies [2–4]. Keys coined the term "Mediterranean Diet" based on his observations of the eating habits of these populations, attributing their health outcomes to their dietary patterns [3, 5].

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The Mediterranean diet is essentially characterized by a high consumption of cereals, legumes, fresh fruit and oilseed fruits, fish and the constant presence of high quantities of vegetables. Additionally, unheated olive oil is the main source of monounsaturated fat. [2, 25]. On the other hand, consumption of potatoes, meat, dairy products, eggs and sugar was moderate [3, 6]. This pattern reflected the characteristic eating habits of several countries in the Mediterranean Basin, such as Portugal, Italy and Greece [7].

In general, consumption of this diet is linked to a lower incidence of non-communicable diseases NCDs), i.e. diseases that are not transmitted through infection or through other people but are typically caused by unhealthy behaviors. Typical NCDs are heart disease, cancer, chronic respiratory diseases, and diabetes. Non communicable diseases kill 41 million people each year, equivalent to more than 7 in 10 deaths worldwide. Is the leading cause of death and represent an emerging threat to global health [8].

In addition to the clinical benefits, there are also ecological benefits. This diet reduces the level of food waste as well as pollution resulting from agriculture [9]. Currently, food waste is one of the biggest problems worldwide. Tons of food are wasted every year. The tendency is to increase over the years, resulting from the combination of inefficient industrial production and population growth [9, 10]. There is an urgent need to find more sustainable strategies to monitor this phenomenon [9, 10].

Many studies have revealed that the Mediterranean diet has a lower environmental impact than other eating patterns. This is because it is primarily a plant-based diet with low consumption of animal products and therefore has a smaller water footprint and lower greenhouse gas emissions compared to another current dietary pattern [11–13]. The adoption of the Mediterranean diet has a marked reduction on all environmental footprint standards [14, 15]. Another relevant aspect is that MD is associated with lower food waste. In Fig. 1, it is shown that food waste has gradually increased over the last few years. The adoption of the MD principles can contribute to revert this trend and reduce food waste.

The Mediterranean diet encourages the use of a wide variety of cereals, fruits and vegetables, not only cultivated products but also wild species, thus sustaining them along with local, indigenous and traditional knowledge about their use. The Mediterranean basin has long been identified as a biodiversity "hotspot," an area with specific concentrations of endemic species and experiencing exceptional habitat loss [15, 16]. The loss of indigenous knowledge about the use of local crops in favor of a small number of non-native species and varieties has affected traditional food production systems and biodiversity throughout the Mediterranean area [15, 17]. Therefore, protect and promote the Mediterranean diets and food is of paramount importance for the conservation of the region's extraordinarily rich biological diversity and vice versa [15, 19]. The seasonal consumption of fresh produce and local products, biodiversity, variety of foods (especially fruits and legumes from different cores), traditional culinary activities, conviviality and frugality represent the cornerstone of conserving the heritage of the Mediterranean diet [15, 19]. This approach leads to lower environmental impacts and supports rich biodiversity in the region.

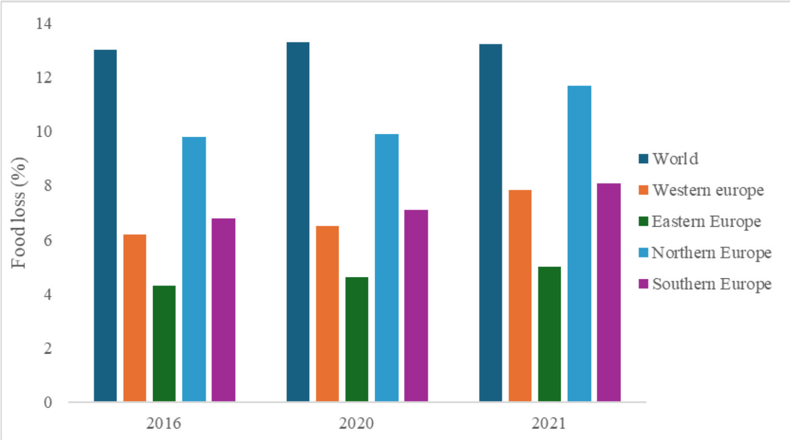

Fig. 1. Food loss in the years 2016, 2020 and 2021. It represents the relative food waste per year per inhabitant before reaching consumers, which ultimately leads to tons of wasted food in each country. Adapted from [1].

2 Soups and Sustainability

Soup is a liquid food made by combining ingredients such as vegetables, grains, legumes, meat or seafood with stock, water, or another liquid base. Soups can vary widely in flavor, consistency, and compositions, making them a versatile and popular option in many cultures around the world. Soups can be served hot or cold and are often enjoyed as a starter or main course.

Soups are recognized as a healthy source of nutrients (mainly proteins, fibers, carbohydrates, vitamins and minerals), bioactive compounds and polyunsaturated fats (olive oil) that help to maintain health and well-being and to control the appetite, contributing to good intestinal health functioning [20]. Another advantage of soups is their affordability, ease of preservation, and simple preparation at home, making them convenient for modern lifestyles. They are often made with natural, eco-friendly, and vegan ingredients, making them a suitable choice for those seeking a healthier diet. Additionally, soups are an ideal option for individuals on a weight loss plan, as they are low in calories but can still provide a sense of fullness [20]. A plate of soup contains 100 g of vegetables, which means that the intake of two plates of soup per day associated with the consumption of three pieces of fruit satisfies the WHO recommendation for the consumption of 400 g/day of fruit and vegetables [20–22].

These typical recipes of the Mediterranean diet are related to the benefits that this diet brings but also to the food sustainability associated with this diet. Soups also allow the development of new strategies to combat food waste since soup recipes often involve using leftovers. Rather than throwing away scraps, they can be transformed into delicious soups, contributing to a more sustainable food system. But also, the use of by-products from the industry as a carrot, for example, that has been broken during the collection process and cannot therefore be sold for direct consumption can be used to produce soups [23, 24].

Consuming soups also leads to a reduction in energy and fuel use (thus leading to a reduction in pollution) [23]. Using locally sourced and seasonal ingredients supports local farmers and minimizes the environmental impact of transporting food over long distances [23, 24]. Soup preparation usually requires less energy than other dishes, leading to lower energy consumption and a smaller carbon footprint, especially when using energy-efficient cooking methods [23, 25]. Soup storage itself is a huge factor against food waste. Because it is possible to make large batches of soup and freezing portions for later consumption can help minimize food waste and encourage meal planning, reducing the likelihood of excess food purchases and spoilage [23].

Overall, incorporating soups into one's diet can align with sustainability goals by promoting the use of local, seasonal ingredients, minimizing food waste, and reducing energy consumption and packaging waste.

3 Health Benefits

Soup can offer several health benefits, depending on the ingredients and the way it is prepared but they have the potential to provide essential vitamins, minerals and antioxidants [20, 26].

In order to maximize the health benefits of soup, opt for homemade varieties made with whole, unprocessed ingredients and limit added salt, sugar and unhealthy fats. Furthermore, soups contain a high-water content, which can contribute to hydration, especially important for those who have difficulty drinking enough water throughout the day [27, 28]. It can also benefit individuals with difficulty digesting food or sensitive stomachs, especially when made with well-cooked vegetables [29]. In this way, they can also be used for weight control, as it can help reduce appetite and reduce overall calorie intake during a meal [30, 31].

The consumption of soups can also benefit the control/prevention of some pathologies such as heart abnormalities [20]. Soups made with lean proteins, whole grains and heart-healthy fats can contribute to a heart-healthy diet by helping to lower cholesterol levels, reduce blood pressure and support overall cardiovascular health [20, 32, 33]. Although more research is needed, some studies suggest that certain soup ingredients may help reduce inflammation and ease cold symptoms [33, 34]. Health and wellbeing can also be achieved via the beneficial action of soups and the microorganisms present in our body [20, 35]. Soups made with fiber-rich ingredients like vegetables, beans, and whole grains can support digestive health by promoting regularity and providing prebiotics that nourish beneficial gut bacteria [20, 35, 36]. Soup, being primarily plant-based, shares the health benefits of the Mediterranean diet, which are linked to longevity and a reduced risk of mortality. It has also been associated with a lower incidence of certain diseases, including cardiovascular diseases and type 2 diabetes mellitus [6, 37–40]. Olive oil, a key ingredient in many soups and a staple of the Mediterranean diet, is known for its anti-inflammatory and antioxidant properties, which can help prevent inflammation and oxidative damage [37–40].

4 Nutritional and Nutraceutical Properties

The benefits described are associated with the various components present in soups and originate from the ingredients used to produce them. These food ingredients can exhibit both nutritional and nutraceutical properties.

Nutritional properties refer to the components of food that provide energy (calories) and essential nutrients necessary for growth, development, and maintenance of bodily functions [41]. These properties include macronutrients, micronutrients, and other bioactive compounds [41, 42]. Understanding the nutritional properties of foods helps individuals make informed dietary choices to meet their nutrient needs and promote overall health and well-being [41, 42].

Nutraceutical properties refer to the bioactive compounds found in foods or dietary supplements that have potential health benefits beyond basic nutrition [41]. These compounds are often associated with promoting health, preventing or managing diseases [41, 43]. Nutraceuticals can be found in a variety of foods, beverages, and dietary supplements [41, 43]. Incorporating a diverse range of nutrient-rich foods into your diet can help ensure you're getting a broad spectrum of beneficial nutraceutical compounds [41, 43].

Soups nutritional properties rely on macronutrients (carbohydrates, proteins and fat), micronutrients (depending on the ingredients used, soups can be rich in essential vitamins and minerals such as vitamin A, vitamin C, vitamin K, B vitamins, potassium, magnesium, iron, and zinc) and fibers (soups containing vegetables, whole grains, and legumes can be a good source of dietary fiber, which supports digestive health, regulates blood sugar levels, and helps maintain a healthy weight) [41, 42].

Furthermore, soups are mainly composed of plant derivatives that introduce unique components into the diet, called phytonutrients [43]. Vegetables, herbs, and spices used in soups contain phytonutrients with various health benefits, including anti-cancer, anti-inflammatory, and immune-boosting properties [20, 43]. Thus, nutraceutical properties are introduced. Many ingredients commonly used in soups, such as vegetables, herbs and spices, contain antioxidants that help protect cells from damage caused by free radicals, reducing the risk of chronic diseases such as cancer, heart disease and diabetes [20]. Some ingredients like garlic have anti-inflammatory properties that can help reduce inflammation in the body and alleviate symptoms of inflammatory diseases like arthritis [20, 41]. Furthermore, the consumption of soups leads to an improvement in the intestinal flora, more specifically the microorganisms present in our body because soups containing ingredients such as onion, garlic, leeks and yogurt can provide prebiotics (fiber that nourishes beneficial intestinal bacteria) or probiotics (beneficial live bacteria) that support gut health and improve digestion and immune function [34, 35].

Soups can be a nutritious and tasty addition to a balanced diet, providing essential nutrients, hydration and potentially beneficial compounds that support overall health. In Fig. 2, the benefits that consuming soup can introduce into the body of those who consume it are represented.

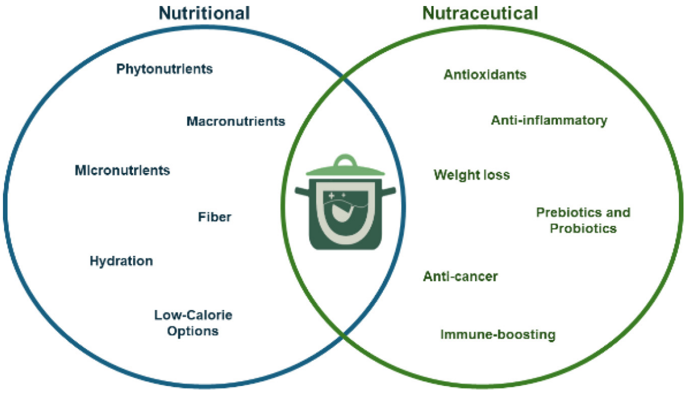

Fig. 2. Nutraceutical and nutritional properties obtained through the consumption of mediterranean soups.

5 Conclusion

The Mediterranean diet is renowned for its health benefits, largely due to its emphasis on vegetables and plant-based foods and convivial aspects. This dietary pattern is associated with healthy aging, thanks to the beneficial components found in its ingredients. Soups, a staple of this diet, exemplify its plant-centric nature and are widely recognized for their health-promoting properties. Furthermore, soup consumption highlights the Mediterranean diet's effectiveness in addressing food waste, a significant issue of our time. In addition to its emphasis on seasonality and fresh ingredients, soups offer sustainability benefits, such as utilizing agricultural by-products and their ease of storage.

Following the bases of the Mediterranean diet, soup offers health benefits, such as the prevention of certain pathologies (cardiovascular diseases or type 2 diabetes mellitus). Furthermore, eating soup improves the body's hydration and is an easily digestible food.

All these advantages are associated with the nutritional and nutraceutical properties of the different compounds present in the soup. Nutritionally, soup is rich in macronutrients, micronutrients, and fiber. However, its primary value lies in the phytonutrients, which provide essential nutraceutical properties, such as antioxidants, anti-cancer, and anti-inflammatory effects.

That said, by consuming soups and following the principles of the Mediterranean diet, it is possible to address food waste while also enjoying the health benefits of these foods. This can contribute to a healthier and more sustainable lifestyle in the long term.

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Soup Was an Emotional Trigger

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Abstract. Soups are one of the most consumed meals around the world. Due to the vegetables used in its preparation, they are recognised as one of the healthiest meals. The consumption of soups provides several health benefits due to the nutritional and nutraceutical properties present in their components. Coincidently, or not, consumption of soup is recommended when individuals are unwell, being considered that it will help recovery. This work consists of preparing a questionnaire for participants in the DM4You project to evaluate the emotions behind the consumption of soups. In an initial approach, 46 volunteers were asked about 3 words that remind them of soup. "*Conforto*" (comfort) was the most repeated word supporting soup as a comfort food. This type of food provides emotional comfort, typically associated with positive emotions such as nostalgia, pleasure, or contentment. Comfort foods are often linked to positive memories or experiences from the past, and consuming them can evoke feelings of warmth, satisfaction, and well-being. As well, the characteristics of the soup such as texture and/or temperature led to an awakening of different emotions through the senses such as taste. The soup itself is still associated with a family celebration present on many dinner tables. As in cultural traditions, they are often passed down from generation to generation. The results presented here will allows us to fine-tune the future questionnaire, several parameters will be selected at an emotional level, making it possible to distinguish the results based on the gender and age of the volunteers.

Keywords: Emotional response · Comfort food

1 Soups: Definition and Characteristics

Soup is a liquid food made by combining ingredients such as vegetables, grain legumes, meat and water, or another liquid base. Soups can vary widely in flavor, consistency and ingredients, making them a versatile and popular dish in many cultures around the

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world [1]. Soups are recognized as a healthy source of nutrients, bioactive compounds and polyunsaturated fats that help to maintain health and well-being and to control the appetite, contributing to good intestinal health functioning [2–4]. A plate of soup contains 100 g of vegetables, which means that the intake of 2 plates of soup per day associated with the consumption of three pieces of fruit satisfies the WHO recommendation for the consumption of 400 g/day of fruit and vegetables [1–4].

The consumption of soups boasts numerous benefits [5], owing to the nutritional richness inherent in their ingredients [5, 6]. These ingredients endow soups with both nutritional and nutraceutical properties [5–7], including coveted attributes such as antioxidants, anti-cancer agents, and anti-aging properties [5–7]. Consequently, incorporating soups into one's diet can potentially mitigate the onset and management of various pathologies, such as heart irregularities and diabetes [8].

Soup, being a liquid food, offers ease of consumption and digestion, rendering it a preferred choice during periods of illness [9, 10]. Beyond its nutritional benefits, soup's hydrating properties further contribute to its efficacy in aiding recovery [6, 7]. Additionally, the comforting nature of soup plays a significant role in its therapeutic effect, often eliciting a sense of well-being and improvement [11]. However, this reaction may also be associated with the fact that soup is considered a comfort food that induces a feeling of improvement [11].

2 Comfort Food and Transmission of Emotions

Comfort food is a term that applies to any food that is consumed with the purpose of providing emotional relief or a feeling of pleasure in fragile situations [11]. Typically, foods classified as comfort foods are associated with significant periods in a person's life or groups considered important to them [11, 12]. These foods are often indulgent, familiar, and rich in flavor, texture, and warmth [11, 12]. Comfort foods vary widely depending on individual preferences, cultural backgrounds, and personal experiences [13]. They are divided into four classes: nostalgic foods, indulgence foods, convenience foods and physical comfort foods [12–14].

Nostalgia food represents that group of foods that are consumed by people who are temporarily away from their family or homeland [15]. This act helps the subject repair their disconnection, which contributes to maintaining sanity in an unfamiliar context [15, 16]. This scenario brings back memories of being cared for by someone you love, or of being with loved ones, both in terms of enjoying the delicacy and preparing it [15, 16].

Indulgence eating is associated with eating without concern regarding the nutritional values or other health aspects of foods and beverages. In this case, pleasure is privileged, and later comes guilt – especially if the consumption is excessive [17, 18]. However, despite the guilt, the pleasure obtained from eating food is interpreted as a form of reward in the face of a sad, distressing or simply unpleasant situation [17, 18].

Convenience foods are those whose main selection criterion is the possibility of immediate access and consumption [19]. In this category, the association between emotional comfort and practicality is essential, and it is possible to see a series of substitutions encouraged by the food industry [19, 20]. Some comfort food scholars claim that this happens for two reasons: either because the person in question was raised in a context of food industrialization and had access to this type of food, or because the socioeconomic context led the person to substitute a homemade product. by an industrialized similar one [19, 20].

And finally, physical comfort foods are those whose composition, temperature and texture provide, in addition to emotional well-being, an improvement in physical state [13]. There are several foods that can be considered comfort foods, one of them being soups.

3 Soup as Comfort Food and Emotion Inducer

Soup is considered a comfort food also belonging to the group of nostalgia foods [11, 15]. Different cultures have their own signature soups, often passed down through generations. Sharing these traditional recipes with loved ones can evoke a deep sense of belonging and connection to one's cultural heritage and family history [11, 15]. Soup-making might be a cherished tradition, with memories of gathering in the kitchen to prepare meals together [21]. Examples of this are "açorda" and "sopa da pedra". But it can also belong to the group of physical comfort foods [13]. In times of illness or distress, soup is often recommended for its nourishing and soothing qualities. A warm bowl of soup is a classic comfort food, especially when the weather turns chilly, or you have a cold [22].

Soup can evoke strong emotions in many individuals in a deeply personal manner. Food often carries strong emotional connections, linked to memories, experiences, and even cultural or familial traditions, thus leading to different emotions and memories [11].

Soup can also be associated with celebrations and rituals [11]. Whether it's a special soup served during holidays, or a recipe reserved for significant life events, the act of sharing soup can foster a sense of joy, camaraderie, and celebration. The act of preparing or receiving a bowl of soup from a caregiver can symbolize love, care, and support, making it an emotional balm during difficult times [11].

In neurological terms, our brains seem primed to make a connection between physical warmth and social warmth [23, 24]. Studies suggest that eating hot soup or even just holding a warm cup of it may increase positive feelings toward others and that extends to other people whom you may see as being culturally different from yourself [11, 23, 24].

Soup, in addition to inducing memories and emotions through the palate, can also do the same through other senses [25]. A soup is normally served hot, which induces an increase in temperature in the consumer, transporting them to a warm or comforting memory [11, 25]. Another sense is smell, all foods transmit smell to the consumer, reminding them of situations in which the smell was present, whether it's at a table with a loved one or in another country [26].

Many studies demonstrate how soup influences the way we act in certain situations and changes our mood. In one study, female college students in Japan who held a warm cup for a few minutes expressed more positive attitudes toward Chinese people, compared to students who held a cold cup [27]. They also showed a greater willingness to help a Chinese individual. In another experiment, people either had chicken noodle soup or not before doing a word-completion task [27]. Those who ate the soup and regarded it as comfort food were more likely to recall relationship words. This suggests that eating the soup may have put them in a more relationship-oriented frame of mind.

Thus, soup can indeed serve as a potent emotional trigger, eliciting a range of feelings and memories tied to comfort, connection, and tradition. The act of enjoying soup can evoke a range of emotional responses based on personal experiences, cultural associations, and sensory perceptions.

4 Questionnaire: Emotional Evaluation of Soups Integrated into the Mediterranean Diet

Currently, the eating habits of the Portuguese population are changing away from the dietary model characteristic of the Mediterranean Diet. The DM4You project (https://dm4you.ipportalegre.pt/) brings together a consortium of several Portuguese partners aiming at the valorization of local foods, namely soups, a basic ancestral food in the Portuguese diet. With the goal to follow the impact of diet, the DM4You consortium will monitor 81 healthy females and males from two age intervals (40–50 years; 60–70 years) over one year following a regimen of soup and fruit consumption.

Through these volunteers, we profit by asking them to evaluate the emotions that are felt through consuming these mediterranean soups. Using a short questionnaire, they were asked to indicate 3 words that reminded them of eating these soups. This survey was answered by 57 volunteers (of both genders) from the Elvas region, for a total of 171 responses. With the results of this survey, Fig. 1 was constructed. In this, it is possible to observe which words are most repeated (the largest) highlighting comfort, satiety and tasty.

Fig. 1. Survey Results (n = 57). In this short questionnaire, volunteers were asked to indicate 3 words they associated with soup. It is important to highlight that the volunteers speak Portuguese. The world cloud was generated at https://wordart.com.

The objective of this exercise was to carry out a first analysis to understand the main emotions that volunteers could feel without selecting emotions a priori to choose from. However, as you can see in Fig. 1, some words do not correspond to emotions. Therefore, in the subsequent questionnaire it will be necessary to provide a list of emotions.

The number of emotions humans can experience is a subject of debate among psychologists and researchers. Some suggest that there are a limited number of basic emotions, such as happiness, sadness, anger, fear, and surprise, while others argue that emotions are more complex and can be categorized in different ways. Some researchers have suggested that there are as many as 27 different emotions [28, 29]. It's important to note that these emotions are not universally recognized or experienced in the same way by all individuals or cultures.

Nevertheless, this questionnaires clearly demonstrate that soup is a comfort food for our volunteers and what emotions it conveys.

5 Conclusion

The consumption of soup is beneficial to health due to the presence of various compounds in the foods used to make it. Soup is also considered a comfort food. In other words, it allows the transfer of emotions and memories to the consumer and belongs to the group of nostalgic foods and foods that improve physical condition. The DM4You project therefore proposes the creation of a questionnaire to be carried out with its 80 volunteers. In this first approach, the most frequently used word was comfort, thus strongly support soup is a comfort food. For the future questionnaire, it will be necessary to know the dietary profile of the volunteers as well as gender and age of the volunteers. They will then be asked to indicate the emotions they associate with soup, according to the profile of 27 emotions.

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Quantification of Food Waste in a Portuguese Nursing Home

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Abstract. Quantification of food waste in nursing homes is essential, identifying the type of care provided to users, ensuring that there is an adequate nutritional supply. The quantification of food waste could be an indicator of the quality of service in these institutions and needs a regular monitoring.

Objectives: Quantification of food waste in a nursing home in the central region of Portugal.

Methodology : Data collection was carried out for 20 days The quantification of food waste was carried out by determining leftovers and plate waste from the meals produced and distributed at lunch time, using the method of selective aggregate weighing.

Results: A total of 260 meals were analyzed, totaling 174,2 kg of food, of which only 62% were consumed. Food waste found in this study is considered unacceptable, as both the leftovers (29.7%) and the plate waste (11.8%) exceed the acceptable limits of 6% and 10% respectively. Regarding meal components, only soup and dessert present acceptable values of plate waste.

Conclusions: High levels of food waste were found, indicating a need to improve meal planning and processing, as well as the adequacy of the menu to the needs, habits and preferences of the elderly.

Keywords: food waste · elderly · plate waste · leftovers

1 Introduction

Food waste, defined as the loss of food in quantity and/or quality resulting from the decisions and actions of producers, distributors and consumers in the food chain, is a major cross-cutting economic and sustainability issue worldwide. Although the planet's resources are beginning to show signs of limitation and finiteness, food waste represents not only the loss of food, but also the waste of the resources used to produce it [1].

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In 2022, the Food and Agriculture Organization of the United Nations (FAO) published its latest report on the State of Food Security and Nutrition in the World (SOFI), which revealed that in 2021 around 828 million people were affected by hunger, concluding that around 3.1 billion people did not have access to safe and healthy food [2].

It is estimated that in Europe around 89 million tons of food are wasted every year, representing a food loss of 30% to 50% of the total value produced. Food waste intensifies essentially at the final stage of the distribution chain, raising social issues related to the current global financial crisis, rising food prices and international food shortages [3].

In Portugal, according to the official national data, 1.9 million tons of food were wasted in 2020, translating into 183.6 kg of food per person, representing 17% of annual production, with around 31% of this figure coming from the distribution and final consumption stage [4].

Regarded as an activity of great social significance, eating is fundamental to health, quality of life and well-being, regardless of age group. In the elderly, a balanced and healthy diet is of great importance during the ageing phase, bringing various benefits, such as reducing bone fragility, increasing immunity and consequently reducing predisposition to metabolic and degenerative diseases [5].

According to official national data, in Portugal there are about 99,000 institutionalized individuals in 2020 [6]. Due to the importance of care provided by nursing homes for elderly, it is necessary to identify the type of care that is provided to users, including the implementation of dietary improvements that guarantee a good nutritional status for this age group [7].

The aging process is often accompanied by various motor, cognitive, physiological, economic, and social changes that can compromise the nutritional status of individuals, leading to various factors influencing eating behavior, such as difficulty chewing and/or swallowing, polymedication, habits and food preferences that are often ingrained, especially in rural areas. To counteract this trend, the nursing homes should present attractive options on their menus that are familiar to users, promoting their acceptability, never neglecting their nutritional needs, avoiding the risk of malnutrition and unintentional weight loss in this age group [8–10]. Because of this condition, there are frequent reports of an increase in falls, chronic wounds, hospital admissions and, consequently, a reduction in quality of life [11].

There are several factors that influence food waste, such as user's food preferences, inappropriate capitations, selection of raw materials, inefficiency of the production system, among others, making it difficult to eradicate. Therefore, quantifying food waste can be used as an indicator of foodservice quality [10].

Objective: Quantification of food waste in a nursing home in the central interior of Portugal.

2 Material and Methods

This study was carried out with the permission of the institution, which has 13 residents, all women with an average age of 92.

The food service was located in a different facility. Meals were prepared approximately two hours before consumption and remained in the oven until distribution. Meals were distributed using insulated and isothermal transport boxes and then served to users at the table in the dining room.

Data collection took place at lunch time over 20 days, to assess the full menu cycle. Food waste was assessed by determining leftovers and plate waste, using the selective aggregate weighing method, in which all components of the meal were weighed separately, namely the soup, the main dish (carbohydrate source, protein source and vegetable source) and the dessert [3].

Leftovers are defined as the food (prepared and cooked) that has not been served to consumers. To evaluate leftovers, all containers were weighed empty and after the plating of meals. At the end of the meal, containers were collected and weighed. The amount of leftovers was determined by the weight difference between initial and final values. The percentage of leftovers was calculated by the ratio of leftovers (g) to the food produced (g). The UK National Health Service Establishment (NHSE) sets the maximum acceptable level of leftovers at 6% [12].

Plate waste refers to the food served to a person but left uneaten on the plate. To evaluate the plate waste, at the end of the meal, the remains on the plates were separated by component and grouped on empty plates to obtain the total value of the waste of each component, eliminating the respective weight of the plates. The weight of the protein source and the fruit was recorded by calculating the edible weight, where applicable, based on the data available at Portuguese Food Composition Table [13]. Food served (g) was determined by the difference between the total food produced (g) and the amount of leftovers (g). Food consumed (g) was calculated by the difference between the amount of food served (g) and plate waste (g). The percentage of plate waste was calculated by the ratio of food uneaten (left on the plate) to the food served to older adults. According to NHSE and to Federal Council of Nutritionists (CFN), values of plate waste below 10% are considered acceptable [12, 14].

Total waste (%) was calculated by the ratio of total waste (leftovers + plate waste) to the total food produced. Food consumed per capita was calculated by the ratio between the food consumed and the number of meals served.

A digital scale (Beurer®, model KS19, North America) with a range of 5kg and an accuracy of 1g, was used for all weighing.

Excel Microsoft Office was used for data analyses. Mean, standard deviations (SD) and maximum and minimum values were used to provide descriptive analysis.

3 Results and Discussion

During the study period, 260 meals were produced, each consisting of soup, main dish (containing carbohydrate source, protein source and vegetable source) and the dessert (raw fruit or sweet), with a total of 174.2 kg of food produced, of which only 62% was consumed (corresponding to a 38% total waste).

Results obtained for food produced and wasted during the study period are presented in Table 1.

Food waste represents 29.7% leftovers and 11,8% plate waste. On average, 2.6 kg was wasted in the form of leftovers and 0.7 kg in the form of plate waste (Table 1). An average of 670g of food was produced per capita and per meal and 414g consumed, i.e. 256g of food wasted per capita and per meal.

Table 1. Food produced and wasted according to the meal component and plate component (n = 20 days x 13 residents = 260 meals (Mean ± SD))

Component		*Food produced (kg)**	*Leftovers (kg)**	*Plate Waste (kg)**	*Leftovers (%)*	*Plate waste (%)*
Soup (n = 20)	Mean ± SD	3,3 ± 0,3	1,0 ± 0,4	0,1 ± 0,1	30,8 ± 9,5	5,3 ± 3,8
	Max	3,9	1,7	0,4	43,8	15,0
	Min	2,6	0,0	0,0	0,9	1,4
CH source (n = 20)	Mean ± SD	1,8 ± 0,6	0,8 ± 0,4	0,3 ± 0,1	43,9 ± 14,4	30,6 ± 13,4
	Max	3,0	1,7	0,5	68,3	48,5
	Min	0,3	0,0	0,0	7,4	4,2
Protein source (n = 20)	Mean ± SD	1,1 ± 0,4	0,3 ± 0,2	0,2 ± 0,1	26,7 ± 17,9	27,1 ± 14,8
	Max	1,9	0,7	0,3	61,9	50,7
	Min	0,6	0,0	0,1	0,0	6,1
Vegetables source (n = 20)	Mean ± SD	0,8 ± 0,3	0,2 ± 0,2	0,1 ± 0,1	22,9 ± 22,9	22,1 ± 13,4
	Max	1,4	0,7	0,3	89,3	65,4
	Min	0,4	0,0	0,0	0,0	3,1
Dessert (n = 20)	Mean ± SD	1,7 ± 0,5	0,3 ± 0,4	0,0 ± 0,0	12,6 ± 14,6	0,0 ± 0,0
	Max	2,9	1,7	0,0	59,1	0,0
	Min	1,0	0,0	0,0	0,0	0,0
Total	Mean ± SD	8,7 ± 1,2	2,6 ± 1,0	0,7 ± 0,2	29,7 ± 8,8	11,8 ± 2,9
	Max	11,5	5,7	1,4	54,3	18,9
	Min	6,5	0,8	0,4	10,1	6,4

*Edible weight. CH source – carbohydrate source

An average value of 30.8% of leftovers was found for **soup** (Fig. 1), with a maximum of 43.8% for Carrot Cream soup and a minimum of 0.9% for Watercress soup. The average value for plate waste was 5.3% (Fig. 2), with a maximum of 15.0% and a minimum of 1.4% for 'Canja' (chicken soup) and 'Caldo verde' (Portuguese green soup) soups, respectively (Table 1).

An average value of 43.9% of leftovers was found for the dish component "**CH source**" (Fig. 1), with a maximum of 68.3% for 'Boiled potatoes' and a minimum of 7.4% for 'Fried potatoes'. As for plate waste, it has an average value of 30.6% (Fig. 2), with a maximum of 48.5% for 'White rice' and a minimum value of 4.2 per cent for 'Fusilli pasta' (Table 1).

Regarding **protein source** component, the average value of leftovers found was 26.7% (Fig. 1), with the highest value found for 'Lasagne' (61.9%) and lowest for 'Meatloaf' (0,0%). The mean value for plate waste was 27.1% (Fig. 2), with the highest value for "Fried horse mackerel" and the lowest value for "Fried breaded fillets" and "Rissoles" (6.1%) (Table 1). When comparing the plate waste between meat and fish, there were no significant differences (Table 2). When comparing the fractionated protein component with the whole protein component, the former presented a lower plate waste value (21.0%) than the latter (31.1%) (Table 2).

An average value of 22.9% of leftovers was found for the **vegetable source** component (Fig. 1), with a maximum of 89.3% for "Mixed salad" and a minimum of 0.0% for "Tomato". The average value found for plate waste was 22.1% (Fig. 2), with a maximum of 65.4% for "Mixed salad" and a minimum of 3.1% for "Green beans" (Table 1).

Regarding **dessert**, an average value of 12.6% of leftovers was found (Fig. 1), with the maximum being 59.1% for the sweet "Papas de carolo" (corn porridge) and the minimum of 0.0% for the fruit "Orange". There was no plate waste for dessert (Table 1).

Table 2. Plate waste for the component "Source of protein", according to type (fish or meat) and presentation (whole or fractionated). Values are mean ± standard deviation.

	Meat (n = 11)	**Fish (n = 9)**	**Whole protein (n = 12)**	**Fractionated protein (n = 8)**
Plate Waste (%)	29,0 ± 13,4	24,7 ± 16,1	31,1 ± 15,1	21,0 ± 12,2

The average value of leftovers for the total meal (29.7%) is well above the acceptable limit (6%) [12] with no component obtaining a value within the acceptable limit. The CH source component present the highest value of leftovers and the dessert the lowest value (Fig. 1).

Concerning plate waste, the average value found for the total meal (11.8%) is slightly above the acceptable limit of 10% [12, 14] and only soup and dessert present a value below the acceptable limit. CH and protein sources are the items with the highest plate waste (Fig. 2).

The total amount of waste found in this study was 38%. A study conducted in Brazil in a hospital setting found that 33% of the food produced was wasted [15]. In Portugal, several studies have assessed food waste in nursing homes, with figures ranging from 19.4 to 36.1 per cent reported [10, 16, 17]. Schiavone et al. (2019) [18] evaluated food waste in three hospitals in Italy and found a total waste of 41.6%.

Similar to this study, several other studies found inadequate levels of leftovers (ranging from 163% to 24,2%) and plate waste (ranging from 12% to 20%) [10, 16, 17, 19].

Leftovers evaluation can be used to assess service efficiency, meal planning and portion adequacy [20]. Therefore, the inadequate values found in this study for leftovers, point out for the need of improvements in the food service. Training should be given

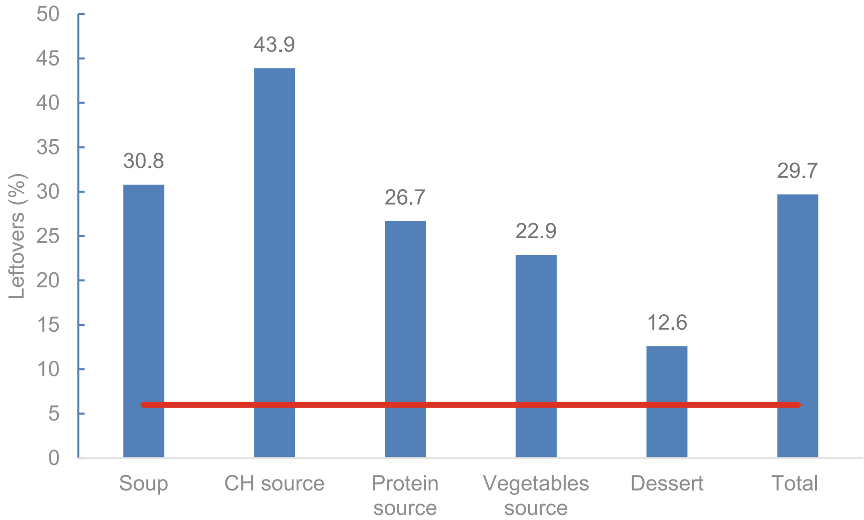

Fig. 1. Leftovers values in relation to the limit value of acceptability (6%, horizontal line) [12].

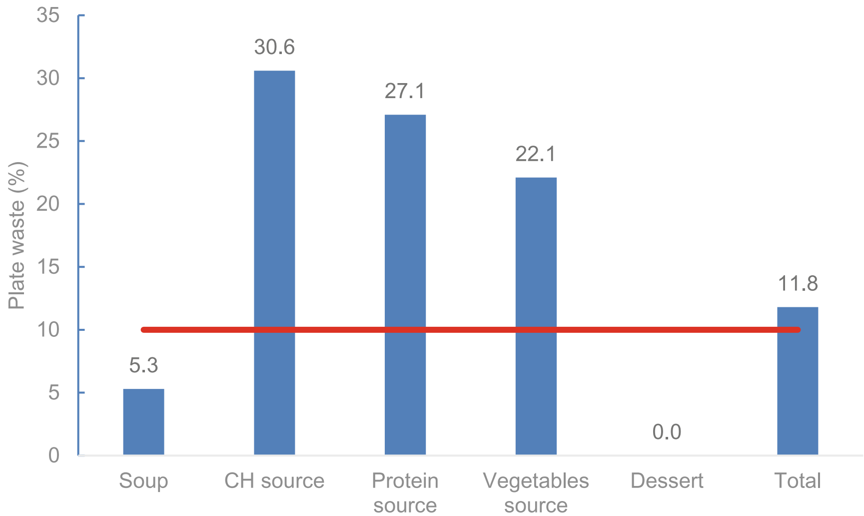

Fig. 2. Plate waste values in relation to the limit value of acceptability (10%, horizontal line) [12, 14].

to kitchen staff, promoting the adjustment of the portions prepared and put out for distribution [21]. Kitchen staff should be trained and encouraged to adjust the portions prepared and served [21]. Food distribution staff should be trained and made aware of the issue of food waste and should accompany users to meals and provide food incentives. A study by Walton et al. (2008) [22] concluded that individualized mealtime assistance and food incentives contributed to a reduction in the amount of waste.

Plate Waste evaluation allows an assessment of the appropriateness of the menu, the portions served and the user's satisfaction with the meal [20].

Only soup and dessert show acceptable levels of plate waste, in line with other studies. "Canja" soup had a higher plate waste value, which may be related to the density of the soup, possibly because it contains pasta, which causes an earlier feeling of satiety, and in this age group a reduced appetite is one of the main reasons for low food intake [21]. Softer foods that require less effort to chew and the fractionated protein presented lower plate waste values, which may be related to the lack of teeth, which makes chewing difficult, and a reduction in the strength of the upper limbs to fractionate the food [21].

The high percentage of plate waste found may also be related to the type of population and its characteristics, which may influence eating behavior, such as eating and cultural habits, and may be influenced by the geographical area. Schmaltz (2018) states that changes in diet and habits affect the acceptability of meals [21]. Other factors to be considered are the waiting time between the production of the meal and its distribution, which can lead to organoleptic changes in the food, and polymedication, which is often associated with decreased appetite and/or anorexia [21, 23]. High values of plate waste observed in this study is of great concern because it may compromise the nutritional intake and contribute to undernutrition, reported as a major problem in this age group [8, 9].

In order to reduce the plate waste, it is important to carry out menu acceptance studies together with the users by carrying out small surveys on satisfaction and food preferences. Involving older people in menu design and recipe suggestions could also be a strategy to reduce food waste. Menus should be adapted to the consumption needs of the elderly, keeping the most acceptable dishes and eliminating dishes presenting higher waste.

The rise in inflation in recent years has had an economic impact on the production and distribution of meals. Considering the average consumption per capita of 414 g, the quantity of wasted meals during the study period could have fed 8 additional person per day. Based on an average cost per meal of €3.05 [24], the daily cost of this food waste amounts to €24.4, resulting in an annual cost of approximately €8,900.

4 Conclusion

Food waste found in this study is considered unacceptable, as both the leftovers (29.7%) and the plate waste (11.8%) exceed the acceptable limits of 6% and 10%, respectively. It is therefore urgent to implement actions to reduce food waste by training staff and adjusting the portions of food produced. It is also necessary to provide meals that suit the tastes and abilities of older people.

Promoting sustainable practices in nursing home food service is crucial for effective management. This involves ensuring healthy and economically viable meals and, at the same time, reducing food waste. It is important that institutions adopt strategies to minimize environmental impact and promote social responsibility.

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Cricket-Based Food Production (*Acheta Domesticus*): Nutritional and Sustainability Considerations, Production Methods and HACCP Implementation – A Narrative Review

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Abstract. As the world's population grows, finding ways to produce enough food to feed people is becoming an increasing challenge. The massification of agricultural production is leading to a gradual and worrying depletion of natural resources and an increase in pollution and environmental degradation. The extensive production of livestock to supply food rich in animal protein leads to huge environmental problems and resource scarcity, and it is therefore urgent to implement effective alternatives to mitigate this scenario.

This narrative review aims to analyse the benefits of producing insects as an alternative animal protein. The production of insects for human and animal food is becoming increasingly relevant as it is less resource intensive and has a low environmental impact compared to the production of other foods. Recent studies have shown several nutritional benefits of crickets, as they contain significant amounts of high-quality proteins, vitamins and minerals. The article also analyses some of the methods used to produce food from house crickets and the strategies implemented to ensure the food safety of these methods and processes. To ensure food safety, critical control points (CCPs) are identified at each stage of production and a Hazard Analysis and Critical Control Point (HACCP) plan is implemented.

Keywords: *Acheta Domesticus* · cricket · nutrition · sustainability · HACCP production

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1 Introduction

The world's population has been growing constantly and exponentially over the last few decades, with an estimated 10 billion inhabitants by 2050. According to the Food and Agriculture Organisation of the United Nations (FAO), it is estimated that this population rise will require an increase in food production of around 60% [1]. Besides the need to increase production, the FAO also highlight other important issues as world hunger, which affects around 900 million people; and food waste, since around 1/3 of the food produced is not consumed [2]. In addition, FAO advises for other constraints of agri-food production, such as: the gradual scarcity of fresh water, with around 700 million people having limited access to water; air pollution through the release of greenhouse gases; climate change, which makes the environment increasingly unstable and unpredictable; natural disasters, pests and diseases, increasingly common events that constantly threaten the agricultural sector and food security [3]. All of these environmental situations are very worrying and could lead to an irreversible and unsustainable global scenario for life as we know it today, as well as serious food insecurity.

The animal's production for human consumption is one of the main sectors of food production that contributes the most to environmental damage. Animals' production involves huge expenditure of natural resources, especially water, and the production of greenhouse gases. Soya is the main source of protein for conventional animal feed, and its mass production has serious consequences for the environment: deforestation, indiscriminate use of pesticides and loss of biodiversity [4]. To mitigate these harmful effects, one of the alternatives is the production of insects for human consumption. Besides environmental advantages, the production of insects for human consumption has high nutritional value, health-promoting properties (antioxidant, anti-inflammatory, anti-diabetic and anti-obesity), and can be safe. In view of its nutritional and environmental advantages, the FAO supports the practice of entomophagy - the act of consuming insects as a food source - as a food source to consider in the future, as a solution to alleviate environmental problems and food insecurity [5]. One of the main challenges of insect-based products commercialisation, such as house crickets, will be consumer acceptance, especially on the European and American continents. Products based on house crickets can also be used to produce feed for farm animals, making them an alternative to soya-based feed, as they are also excellent sources of protein [4].

This review will focus on the production methods of foods based on house crickets, the hazards and the precautions to be taken at each stage of production to ensure the food safety of the product. This review will also look at the nutritional qualities and benefits of introducing insect-based products into the diet. Consideration will be given to how an increase in the production of insects for human consumption and a consequent reduction in the rearing of other animals can have an impact on environmental issues.

Scientific papers were searched in PubMed and ScienceDirect databases between April and May 2023, using the following keywords: "*Acheta domesticus*" with the Boolean operator "AND" and the following keywords "nutrition", "food pro-duction", "HACCP" and "sustainability". The total number of results obtained by linking the key-words in the two databases was 2228. The results were filtered by year of publication, title, abstract and results. A total of 42 articles were obtained from this filtering and used for this narrative review.

2 House Cricket Food Production

The production of insects for human consumption is still underexplored in Europe and the United States, and is mainly exploited for the production of pet food (reptiles and amphibians), fish feed, in zoos, by pest control companies (bio-control), and some aquaculture companies. Some Asian countries such as China and Thailand already have medium to large-scale manufacturing of insects for human consumption and medicinal purposes. However, entomophagy has gained prominence in Europe and America over the last decade and an increasing number of companies are specialising in the production of insects for human and animal consumption [6].

The FAO estimates that approximately 2.5 billion people eat insects regularly around the world. This is due to their abundance and ease of capture, as well as their nutritional properties. The growing interest in the consumption of insect-based foods has led some companies to develop techniques and technologies to produce them on a large scale. However, as with any food product, it is extremely important that legal health and hygiene regulations are strictly adhered to. Aspects such as microbiological safety, toxicity, palatability and the presence of inorganic compounds must be taken into account. These requirements must be put into practice, as not all sectors breed and produce insects and insect-based foods in a way that ensures safety [7].

Like any company that produces food for human consumption, it must have a health plan that complies with food safety standards and good manufacturing practices (GMP), which are regulated by the European Food Safety Authority (EFSA). The applicable legal document is Regulation 2015/2283. When processing food based on any insect species, programmes must be put in place to meet the requirements of the HACCP system, such as cleaning and disinfection, pest control, solid waste, drinking water, preventive maintenance, supplier control and traceability.

In Europe and North America, the production of insects for human consumption is a very young market, but it is growing, particularly in the production of insects that undergo a dehydration process to be eaten whole or used as ingredients to make insect-based products such as snacks, pastes, flours, biscuits, sweets, protein bars or sausages [7–11].

The processing method of house crickets is different from other insects, such as the larvae of *Tenebrio molitor,* but similar to others, such as grasshoppers [7]. The first step after receiving the adult crickets is to slaughter them. Slaughtering crickets is a simpler process than slaughtering livestock, as it involves first fasting the crickets for about 24 h to reduce the intestinal content, as removing the intestines is an expensive and difficult procedure. The temperature is then lowered to −18 °C to −20 °C for 24 h [7, 12]. In some more traditional markets, insects such as crickets can be sold whole. However, for the production of insect-based products, it is more common to remove the legs and wings after slaughter, especially in the case of crickets and grasshoppers [7].

After this last step, it is up to the producer to decide what type of product they want to make with the crickets, as the next steps will vary depending on the final product desired. The industry is interested in three types of product: dried whole insects with spices, salted, sweetened or natural; paste obtained by grinding the crickets, which is used to produce meat-like foods such as hamburgers or sausages; flour obtained by grinding the dried crickets, which can be sold as flour or used as an ingredient in the production of bread, biscuits or protein bars [7].

Insects such as crickets have a very active microbiota. The next step is to significantly reduce this microflora by cooking the crickets for 1–5 min in boiling water, or they can be cooked in a pre-seasoned broth to give the product the desired sensory characteristics. The temperature and time of cooking must be taken into account to avoid significant nutritional losses. Once the water has been drained off, the insects are cooled and must quickly reach a chilling temperature to prevent the multiplication of pathogenic microorganisms. Crickets and other insects should not be stored at room temperature to prevent decomposition [7, 13].

In products where it is necessary to use drying technology, crickets and other insects are placed in ovens and exposed to a temperature ranging from 60 °C to 100 °C. During the drying treatment, the water retained in the crickets is removed, resulting in a reduction in microbial proliferation [7, 14, 15].

A very viable alternative to conventional drying is freeze-drying. Both drying and freeze-drying play a fundamental role in reducing the water activity in a food. Freeze-drying is a process carried out in a freeze-dryer, which is able to remove water directly from the frozen insect. This process results in less nutritional and sensory loss and, as it is carried out at very low temperatures, there is no chance of microbial growth [7, 16].

To produce cricket flour, crickets are dried, ground to the desired size and then sieved. All the additional processes for cricket flour are similar to those for conventional flour [7, 17].

If the producer's intention is to make meat-like foods such as hamburgers and sausages, the method used is to mince the insect after cooking. Once the crickets have been minced, they are mixed with other ingredients to make them more similar to meat products from a sensory point of view. This type of product is a great tool for overcoming new consumer aversions to insect-based products. This method of producing cricket-based food results in a product with a high-water activity (high water content) and pH, which means it is much more perishable than the drying method. It is therefore necessary to pay attention to the way these products are stored, as they need to be kept in a refrigerated environment or even frozen [7, 18–20].

Each of the above methods requires proper packaging to avoid contamination or other hazards that could compromise the food safety of the product. In the case of crickets, as with other edible insects, their high lipid composition requires packaging in a modified atmosphere to prevent or retard lipid oxidation [7, 21].

These insect-based food industries are also able to master certain processing techniques and technologies that allow the separation of fractions of particular nutritional interest [7].

According to Psarianos et al., Pulsed Electrical Field (PEF) treatment is a method that can improve the functional properties of cricket meal and help to separate its major nutritional components such as protein, fat and fibre. However, this study also confirms that PEF treatment of crickets may not have the desired economic viability and sustainability, so more future studies are needed to differentiate between these factors [22].

3 Implementation of HACCP Principles

HACCP (Hazard Analysis Critical Control Points) is a tool for identifying specific potential hazards that could cause harm to consumers, and for preventing and eliminating these hazards through a control system that can guarantee food safety [7, 23].

In the sector of food production based on crickets and other edible insects, it is necessary to implement preventive measures in primary production areas as well as in the specialised area of cricket-based food processing. Although the application of HACCP principles in primary production is not mandatory in the European Union, it is recommended to follow certain general principles established in food safety regulations, such as Good Hygiene Practices (GHP), Good Veterinary Practices (GVP) and Good Agricultural Practices (GAP). These types of practices used to promote food safety can also be referred to in HACCP methodologies as a prerequisite programme. With regard to food processing, the application of HACCP is mandatory, particularly in the identification of hazards that could compromise the food safety of the product, the hygiene of facilities and equipment and maintenance programmes to avoid cross-contamination, the proliferation of pathogens and dangerous chemical products [7, 24].

There are microbial risks associated with insects, particularly house crickets. The microbiota of insects is known to be very active and abundant and can act as a vector for microorganisms that are dangerous to humans. The microbiota of insects, as in the case of house crickets, may contain the following pathogens *Staphylococcus*, *Streptococcus*, *Enterobacteriaceae*, *Micrococcus*, *Lactobacillus* and *Acinetobacte*, *Bacillus*, *Pseudomonas*. Other pathogens such as *Campylobacter*, *Escherichia coli* and *Salmonella* can be found in crickets and other unprocessed insects. Although less obvious, crickets can also carry viruses, parasites, fungi and yeasts that can be harmful to human health. It is therefore very important that all processing steps are carried out correctly. [7, 25–28].

With regard to chemical hazards in the production and processing of cricket-based foods, they may contain various chemical and biochemical substances that can be toxic. The following toxins can be found in the composition of crickets or cricket-based foods: mycotoxins, aflatoxins, dioxins, organochlorine compounds, polybrominated diphenyl ethers (PBDEs) and heavy metals such as cadmium, lead, arsenic, zinc and copper. This chemical contamination can result from inappropriate farming practices and the misuse of pesticides and antibiotics [7, 29, 30].

Physical hazards in the processing of cricket-based foods consist of all kinds of foreign bodies that can cause injury to consumers. The most common physical hazards in these cases are contamination of the food with metal or plastic parts. Parts of the crickets that should have been discarded, such as wings and legs, may also be retained in the final product [7].

4 Nutritional Considerations for House Crickets

The nutritional profile of insects varies mainly between species. However, even within species, their nutritional composition can vary depending on their diet, type of farming, metamorphic stage, habitat and type of processing [31].

In any case, the nutritional profile of house crickets is generally high in protein, essential amino acids, omega-6 and omega-3 fatty acids, fibre, vitamins and minerals [31].

4.1 Protein Content

Protein is one of the most abundant macronutrients in any insect species. As mentioned above, the composition of protein in crickets, as in any insect, can vary. The type of processing is one of the main factors that determines the amount of protein in crickets. This is because in crickets that have not been dried, the main component is water, which can make up from 52% to 79% of their constitution, and the amount of protein is from 13% to 25%. However, if the cricket is subjected to a drying process, the water is reduced to almost residual amounts of 0.6–9%. Protein, on the other hand, becomes the dominant compound and can increase by almost six times compared to crickets that have not been subjected to a drying process, with values of 42–75% [32].

House crickets, like other edible insects, are generally of excellent protein quality. This means that they have all the essential amino acids in their composition and in optimal amounts, very close to the FAO recommendations. The essential amino acid composition doesn't vary much between insect species, but house crickets are one of the species with the highest levels of all essential amino acids [31, 33, 34].

4.2 Fat Content

The total fat content also depends on the type of processing, but the percentage of crude fat in house crickets is 1.6–18%. House crickets contain both families of fatty acids: saturated and unsaturated. The levels of saturated, monounsaturated and polyunsaturated fatty acids are similar. Although crickets contain a relatively high amount of saturated fatty acids (palmitic acid accounts for 26% of total fatty acids), total unsaturated fatty acids (monounsaturated and polyunsaturated fatty acids) are more common. The predominant fatty acid in house crickets is linoleic acid, from the omega-6 family (polyunsaturated fatty acid), which accounts for 35% of total fatty acids. Oleic acid (omega-9), which is a monounsaturated fatty acid, is also present in high amounts, around 24% of the total fatty acid content. House crickets are also a source of omega-3 [31, 32, 35, 36].

4.3 Fibre Content

Dietary fibre is also one of the main nutritional components of house crickets, accounting for 1–6% of their composition, depending on the type of processing and other factors. Dietary fibre plays several roles, particularly in maintaining the health and functioning of the digestive system. In insects, particularly crickets, dietary fibre is mainly in the form of chitin, a polysaccharide that forms the structure of the exoskeleton. Although not fully agreed, some studies suggest that house crickets are not the edible insect species with the highest fibre content [4, 32, 33, 36, 37].

4.4 Vitamin and Mineral Content

House crickets are a very interesting source of micronutrients. The vitamin and mineral content of house crickets also varies depending on the processing method and other farming factors. The main vitamins present in crickets are B-complex vitamins such as riboflavin (B2), pantothenic acid (B5), biotin (B7), folic acid (B9) and cobalamin (B12), as well as vitamins C, A, E and K. Vitamin B12 is one of the most lost vitamins, depending on the type of processing, e.g. drying results in almost total loss of cobalamin. The main minerals found in crickets are iron, magnesium, manganese, copper, selenium, zinc and phosphorus. In the case of minerals, dried crickets appear to have a higher mineral content than crickets or cricket-based foods that have not been dried [31, 32, 34, 36].

5 Sustainability Considerations

The increased demand for animal protein-based foods, driven by population growth and other factors, is leading to environmental degradation on a global scale. Habitat destruction, agricultural over-exploitation, climate change, greenhouse gas emissions and water waste are the main consequences of the mass production of animal protein-based foods [38, 39].

The production of insects, such as crickets, for human consumption is seen as a solution to alleviate and mitigate the damage caused by the overproduction of animal protein foods. Their high nutritional value and simpler and cheaper rearing and production methods compared to other animal proteins make insect-based foods interesting products. In addition, the production of insect-based products has been shown to have a much lower environmental impact than other animal proteins [37–39].

Compared to the various types of meat produced, rearing and processing insects results in much lower water costs, carbon emissions and land requirements. For water footprint, 1 g of chicken protein can be 2 times higher than crickets and 5 times higher than beef. Regarding land requirements, chicken protein could require 2–3 times more land than insect protein, while beef protein could require 8–14 times more land. In terms of carbon emissions, chicken protein could mean an increase of around 1.5 times, while beef protein emits 6 to 13 times more carbon [38, 40, 41].

Insects such as crickets can also play a fundamental role in food waste. Around 1/3 of food is wasted and this could be used to produce biomass to feed house crickets, helping to reduce food waste and therefore overproduction and environmental degradation [42].

6 Conclusion

The production of insects for human and animal consumption is becoming increasingly important in the European and American markets. The aim of this review was to analyse nutritional considerations, sustainability, production methods and the implementation of HACCP methodologies.

House cricket production could also play an important role in several environmental issues. Conventional animal protein production is associated with environmental degradation such as: deforestation, loss of biodiversity, pollution and huge consumption of water and land. On the other hand, the breeding of house crickets for consumption can be carried out in specific, controlled environments, reducing the impact on the environment. They also require fewer natural resources and have a much smaller carbon footprint than other animal proteins.

House crickets have a very interesting nutritional composition. They are an excellent source of protein, containing all essential amino acids, unsaturated fats such as omega-3 and omega-6, and fibre. They are also an excellent source of vitamins, especially B vitamins, and minerals such as iron and calcium. The inclusion of house crickets in the diet could contribute to greater dietary and nutritional diversity.

By using less water, feed and space for rearing, and combining production and processing methods that are simpler and cheaper than other conventional animal proteins, cricket production could be a viable, economical, healthy and safe solution to introduce in the European and American markets.

Further studies are needed to determine how the expansion of cricket and other insect production may affect the environment, food safety and nutritional benefits for humans and animals.

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Similarity as the Main Indicator of Seed Quality

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Abstract. Corn cultivation is an important component of the grain industryin any agricultural country. Corn is characterized by its versatility and high yield. One of the most important prerequisites for obtaining high yields is planting with high-quality seed material. Similarity is the main indicator of seed quality. The formation of similarity depends on a number of factors that affect the plant and grain during ripening. These factors include the dynamics of moisture release and accumulation of dry matter, as well as the moisture content at which the seeds are harvested. During the research, features the ripening of corn hybrids were established and the humidity at which seed germination was formed was determined. It was established that at a moisture content of 50–51%, the grain contains 71–83% of the maximum possible dry matter. The maximum content was recorded at a humidity of 30–33%. Laboratory similarity wasformed at a moisture content of 47.2–53.5% and below, depending on the hybrids. It was found that seed moisture release compared to previous multi-year data has significantly increased, ranging from 0.8–2.3% per daydepending on the hybrids. The accumulation of the main mass of dry matter is completed at a moisture content of 22–30%. At a moisture content of 32–40%, the seeds already reach high field similarity and productivity depending on the maturity group of the hybrids.

Keywords: corn · seeds · quality · similarity · productivity

1 Introduction

In recent years, there has been a dynamic growth of market relations world wide, which directly affects agriculture and its development. Corn cultivation is an important component of agricultural development and the grain industry in any country. Corn is a unique raw material for the food, medical, microbiological, processing industries, and a high-energy raw material in bioethanol production.

2 Seed Germination Is the Main Indicator of Quality

Plating with high-quality seeds, under favorable weather and soil conditions at optimal sowing times, is the first and one of the most important prerequisites for obtaining high yields. According to the basic regulatory and legal documents that operate in the field of seed production, only conditioned seeds that meet the requirements for variety and

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sowing qualities are allowed for planting [1, 2]. Seed qualities include the following indicators: purity (main seed content); weight of 1000 seeds, or coarseness; germination energy and similarity; vitality and moisture. When determining the quality of the seed, the level of its damage by diseases and pest infestation is also monitored. The main indicator of seed quality is its similarity - the percentage of seeds capable of producing healthy, strong, undamaged seedlings that can develop into normal plantsunder optimal field conditions.

Similarity is the main indicator of seed quality, which mostly characterizes its suitability for sowing, productivity, and has important practical significance among all seed indicators. It has been proven that only by planting seeds with high similarity, established by the standard, can quick and friendly seedlings be obtained. Seeds grown in different years, even with the same sowing qualities, often differ in similarity indicators. The formation of similarity depends significantly on the conditions and biotic-abiotic factors that occur during its ripening, harvesting and post-harvest processing. The main factors during ripening include the dynamics of moisture release and accumulation of dry matter, as well as moisute content at which the seeds are harvested. The conditions that affect the intensity of moisture release and harvesting moisture act comprehensively. These include temperature regime and precipitation during the vegetation period,hybrid maturity group and phase, grain and cob structure,and characteristics [3, 4].

Seeds carry the biological and economic properties of plants, therefore, the yield that can be obtained when sowing them largely depends on its quality. During its germinationand subsequentsimilarityformation, seeds require the presence or creation of those life factors that ensure their further development. Life factors are environmental objects that directly (materially) affect the growth and development of plants [5, 6]. Maximum germination abilityoccurs when the seed reaches physiological maturity. It, first of all, depends on the external environmentconditions during the seed development and ripening on the parent plant. Deterioration of seed quality after ripening under ideal conditions is often caused by other reasons. Changes in seed quality are also observed during harvesting (especially mechanized), post-harvest processing, as well as storage (under the influence of microorganisms and insects). Changes usually lead to a deterioration in the quality anssimilarity of seeds. At the same time, in addition to the direct effects (damage by insects, fungalmold), seed resistance weakens, its growth strength and germination energy decrease. Also, physical abnormalities and special physiological processes (self-heating, intenserespiration, accelerated consumption of reserves) also begin in the seed mass [5].

Often, the field similarity of seeds of thermophilic plants is significantly lower than thelaboratory similarity due to the action pathogenic microorganisms on them in cold soil conditions [6]. Immature seeds, in contrast to fully ripened ones, are much more damaged by pathogenic microflora, especially when sown in insufficiently warmed soil. In recent years, the climatic conditions for growing agricultural crops have changed significantly. Also, many different factors affect the timing of planting, timely care, and predicted harvest dates. Spring can be cold and prolonged, which will delay the time of planting; or dry, not providing enough moisture seedlings; dry summer or early cold autumn. This directly affects the formation of grain, corn ripening, seed moisture release, the process of seed formation and similarity formation. The formation of seed qualities of corn seeds during cold (autumn) weather can affect the quality, including the similarity of the formed grain. It has been established that the average daily seed moisture release of corn is to some what related to its maturity phase and moisture content [7]. It was noted that when corn is harvested with a moisture content of 30–40% in the grain, the accumulation of dry matter is practically completed, reaching its maximum, the seed becomes fully formed in terms of sowing and yield properties and can have a high level of conditionality, but under optimal conditions of post-harvest processing [8, 9]. Seed weight is a factor that characterizes its strength, as it more accurately reflects the reserves of nutrients used during germination. It has been proven that more productive plants are always formed from large seeds [10, 11].

The aim of our research was to establish the ripeningcharacteristics of corn hybrids and determine the moisture content at which conditioned seed similarity is formed. The research was conducted at the Institute of Agriculture of the Steppe Zone of the National Academy of Sciences of Ukraine. The ripening process was studied on corn hybrids selected by the Institute, which belonged to different maturity groups: Dniprovsky 181 SV, Kremin 200 SV, Lyubava 279 MV, Rozivskyi 311 SV.

Corn cobs for the research were selected at the milky-waxy ripeness stage, starting from a moisture content of 50–65% depending on the hybrids and the conditions of the year. The harvested cobs were immediately freed from husks, and the seed moisture content was determined. Later, the cobs were dried, threshed in the laboratory, and seed samples were prepared for analysis. In laboratory experiments, such indicators of seed quality as germination energy, laboratory and cold similarity, weight of one thousand grains and absolute dry weight were determined [2].

Field similarity and grain yield were studied according to the requirements of the methodology for conducting corn research [12]. During the ripening of corn, the seed formation process and the formation of its similarity were accompanied by moisture release and the dynamics of dry matter accumulation. The average daily seed moisture release of corn hybrids was different and changed depending on weather conditions. Compared to previous multi-year data, the moisture yield was quite high during the entire drying period, ranging from 0.8–2.3% with a decrease in moisture from 50.7 to 19.5% (Table 1).

Table 1. Grain moisture yield by corn hybrids during the ripening-drying period.

Hybrid	Grain moisture during the drying period, %		Average duration of the period, days	Daily moisture yield of grain, %
	Beginning	End		
Dniprovsky 181 SV	45–50	17–20	27	0.93–1.00
Kremin 200 SV	47–57	19–22	26	0.80–1.88
Lyubava 279 MV	50–60	20–23	31	0.89–1.85
Rozivskyi 311 SV	51–64	20–23	36	0.86–2.30

To study the productivity of maize hybrids, along with the moisture yield, the dynamics of growth of the mass of 1000 seeds and accumulation of dry matter were determined simultaneously (Table 2). For this purpose, the mass of 1000 seeds was recalculated to 14% moisture content.

Table 2. Dynamics of germination and accumulation of dry matter by seeds of corn hybrids.

Hybrid	Grain moisture, %	Germination, %		Weight of 1000 seeds, g	
		Energy	Similarity	Actual	Absolute
Dniprovsky 181 SV	60.6	77	77	137.2	125.7
	56.5	86	87	140.1	121.0
	53.5	88	92	157.6	140.3
	48.9	94	96	179.5	155.8
Kremin 200 SV	57.8	63	63	130.5	116.1
	51.4	99	99	184.5	166.1
	49.2	97	97	194.4	167.2
Lyubava 279 MV	60.9	69	76	97.0	87.7
	58.4	73	76	151.7	135.6
	51.3	94	96	187.1	162.0
Rozivskyi 11 SV	67.0	57	59	106.7	96.0
	64.3	71	74	137.3	125.2
	47.2	95	95	267.6	231.8

During the ripening period, the mass of the seeds increases, indicating the formation of sowing qualities. Comparing the actual mass of 1000 grains with the one registered in the hybrid characteristics, we can confidently speak about the seed formation. It was found that at a moisture content of 53.5–51.3%, the grain contains 71–83% of the maximum possible dry matter. The maximum content was recorded at a moisture content of 30–33%, depending on the hybrids. The similarity of maize seeds was studied starting from amoisture content of 57.8–67.0%. Conditional similarity of not less than 92% was formed already at a moisture content of 47.2–53.5% and lower, depending on the hybrids. The similarity was determined according to the standard method, which is carried out under ideal germination conditions. It can be confidently stated that such similarity indicates to a greater extent the viability of the seeds and may be completely different in field conditions. Analyzing the obtained data, it can be stated that the process of seed formation of the investigated hybrids mostly ended at the indicated moisture content, as seed similarity reached the norm (92%). But at the moment of reaching conditional similarity, the accumulation of dry matter does not end, meaning the grain formation is still ongoing. For example, at a harvest moisture contentof 47.2–51.3%, the content of dry matter is 20.1–34.8% lower, compared to the maximum possible, and the growth of the seed mass is still being recorded. Therefore, further research was carried out at a seed moisture content of 47.2–53.5% (Table 3). The selected maize cobs were dried at a temperature of 30 ˚C with subsequent threshing. The seeds were germinated using standard and cold methods, and their field similarity and yield were also studied.

Table 3. Sowing and yield properties of corn hybrid seeds depending on their harvesting humidity.

Hybrid	Grain moisture,%	Germination, %			Seed yield, t/ha
		Standard-method	Cold test	Field	
Dniprovsky 181 SV	53.5	91	41	57	3.8
	45.9	99	90	83	6.4
	30.9	98	90	85	6.0
	20.4	98	93	85	6.5
	$NIR_{0.5}$			3.2	0.2
Kremin 200 SV	51.4	99	41	65	5.3
	45.2	100	56	80	6.3
	31.7	98	85	84	6.9
	22.6	98	88	84	7.1
	$NIR_{0.5}$			2.8	0.4
Lyubava 279 MV	51.3	96	43	63	5.9
	40.0	95	75	75	5.8
	32.3	96	78	78	7.6
	22.7	95	80	81	7.5
	$NIR_{0.5}$			2.1	0.3
Rozivskyi 311 SV	47.2	95	78	80	6.9
	40.5	98	86	81	6.9
	29.8	98	84	81	6.6
	21.3	98	86	82	6.7
	$NIR_{0.5}$			2.7	0.2

According to the standard method of germination, the seeds were practically of the same quality in terms of similarity within harvest moisture contentrange of 20.4–53.5%. With cold germination, the similarity was more differentiated and depended on the hybrids. For the hybrids Dniprovskyi 181 SV and Rozivskyi 311 SV, high similarity was already observed at harvest with moisture content of 45.9 and 40.5%, respectively, while for the hybrids Kremin 200 SV and Lyubava 279 MV, it was 31.7 and 32.3%, respectively. Similarly, field germination and seed yield were formed.

3 Conclusions

It was found that in conditions of climate warming, the moisture yield has significantlyincreased and amounts to 0.8–2.3% per day, depending on the hybrids, and is higher compared to long-term data. The accumulation of the main mass of dry matter is completed at a moisture content of 22–30%. It was established that the conditional similarity of the seeds of the studied hybrids is alreadyreached at a moisture content of 47–53%. High field similarity and productivity are observed at a moisture content of 32–40%, depending on the hybrids. It is recommended to harvest seed crops of corn hybrids of different maturity groups with the following moisture intervals: 38–40; 30–32; 22–20%, when the seed quality indicators are already formed.

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