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Procedia Environmental Science, Engineering and Management (P - ESEM) is a journal focusing on publishing papers selected from high quality conference proceedings, with emphasis on relevant topics associated to environmental science and engineering, as well as to specific management issues in the area of environmental protection and monitoring.

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GUEST EDITOR

Fabio Fava, born in 1963, is Full Professor of “Industrial & Environmental Biotechnology” at the School of Engineering of University of Bologna since 2005.
F. Fava published about 250 scientific papers, 180 of which on medium/high IF peer-review international journals of industrial and environmental biotechnology and circular bioeconomy. He has 8680 overall citations, a h-index of 55 and an i10 index of 145 (Google Scholar) along with 180 papers quoted by Scopus. He is actively working in the fields of environmental, industrial and marine biotechnology and of the circular bioeconomy in the frame of a number of national projects and collaborative projects funded by the European Commission. Among the latter, he coordinated the FP7 collaborative projects NAMASTE, on the integrated exploitation of citrus and cereal processing byproducts with the production of food ingredients and new food products, and BIOCLEAN, aiming at the development of biotechnological processes and strategies for the biodegradation and the tailored depolymerization of wastes from the major oil-deriving plastics, both in terrestrial and marine habitats.
He also coordinated the Unit of the University of Bologna who participated in the FP7 collaborative projects ECOBIOCAP, ROUTES, MINOTAURUS, WATER4CROPS, ULIXES and KILL SPILL.
F. Fava served and is serving several national, European and international panels, by covering, among others, the following positions:
• Member of the Scientific Committee of the European Environmental Agency (EEA), Copenaghen, for the "Circular economy and resource use" domain (2021-);
• Italian Representative in the "European Bioeconomy Policy Forum" and the "European Bioeconomy Policy Support Facility" of the European Commission (2020-);
• Italian Representative in the Horizon2020 Programme Committee of Societal Challenge 2: European Bioeconomy Challenges: Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and inland water research" (European Commission, DG RTD) (2013-);
• Italian Representative in the "States Representatives Group" (SRG) of the Public Private Partnership "Biobased Industry" (PPP BBI JU) (Brussels) (2014-); he is chairing the SRG since October 2018;
• Italian Representative in the BLUEMED WG of the EURO-MED Group of Senior Officials (EU Commission DG RTD and Union for Mediterranean) (2017-);
• Italian Representative in the initiative on sustainable development of the blue economy in the western Mediterranean the "Western Mediterranean Initiative" WEST MED, promoted by the EU Commission (DG MARE) in close cooperation with 10 countries of the area (2016-);
• Italian Representative in the "Working Party on Biotechnology, Nanotechnology and Converging Technologies" of the Organization for Economic Co-operation and Development (OECD, Paris) (2008-);
• Chair (2011-2013) and currently Deputy Chair of the "Environmental Biotechnology Section" of European Federation of Biotechnology (EFB) (2013-).
Finally, he is the scientific coordinator of the International Exhibition on Green and Circular economy ECOMONDO held yearly in Rimini (Italy)

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INNOVATIVE SENSORS TO DETECT THE RIPENING STAGE OF TOMATO FRUITS FOR EFFICIENT CROPS CONTROL IN SMART GREENHOUSES*

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Abstract

In recent years, with the emerging of the Internet-of-Things (IoT) and its application to different fields, smart technologies have been applied to agriculture with the aim to reduce water resources and power consumption as well as to increase the crops yield. Thus, smart greenhouses equipped with a set of sensors have been developed that exploit solar panels to generate the needed electrical power, use smart irrigation systems to minimize the water consumption and optimize plant growth by regulation of light, humidity and heat.

In the context of smart control of crops, the determination of the ripening stage of fruits and vegetables is of primary importance to maximize crops production and minimize waste in both pre-harvest and post-harvest stage. Ripening stage determination is usually carried out by visual inspection and firmness evaluation by an operator, techniques that are both subjective and prone to errors. Thus, there is the need of innovative methods to evaluate the ripening stage of fruits and vegetables that must be inexpensive, reliable, accurate and suitable to be integrated in a sensor network.

In this work, Electrical Impedance Spectroscopy (EIS) is investigated as a technique to evaluate tomato ripening in the post-harvest stage. Three different sensor configurations, suitable for destructive and non-destructive tests, different in terms of electrodes type and accuracy, are presented. The results show that the application of EIS for the automatic evaluation of tomato ripening stage is feasible and can be implemented to increase crops yield in smart greenhouses.

Keywords: food sensors, electrical impedance spectroscopy, internet of things, smart greenhouse

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1. Introduction

In recent years intensive research has been carried out on the application of smart technologies to agriculture in the paradigm of the Internet of Things (IoT) (Kour and Arora, 2020; Tzounis et al., 2017). Thus, smart greenhouses have been developed that integrate sensors and actuators for in-the-field monitoring, wireless transmission protocols (such as Bluetooth and Wi-fi) to transfer the measured data to a remote host and powerful processors for intensive data processing. For example, plant growth can be optimized by the use of sensors such as temperature, humidity and light sensors to monitor the environmental conditions (Hu and Qian, 2011; Nassar et al., 2018). Strain sensors can be exploited for dynamic measurement of plant growth (Tang et al., 2019), high resolution cameras and image processing techniques can be used to collect data for quantitative studies of complex traits related to the growth, yield and adaptation to biotic or abiotic stress (Li et al., 2014), and chemical sensors can be used for assessments of main plant nutrition components, pollutants, and other important soil parameters (Nadporozhskaya et al., 2022). Moreover, smart irrigation systems based on IoT can exploit the deployed set of sensors for efficient water management to reduce the use of water and optimize plant growth (Obaideen et al., 2022). A key point of modern smart greenhouses is also energy efficiency. The energy required to operate the sensors and actuators can be scavenged by natural sources (such as solar, mechanical, heath, biochemical) (Grossi, 2021). In the case of light energy, for example, solar panels can be used to power the systems in the greenhouse and even store the surplus energy to consume it during night or during unfavorable weather conditions (Wangmo et al., 2020).

Many examples of sensor technologies applied to agricultural products in both pre-harvest and post-harvest stage can be found in literature. Zhang et al. in 2019 investigated the possibility to use a commercial instrument (GreenSeeker) to predict grain yield of winter wheat (*Triticum aestivum* L.) (Zhang et al., 2019). Grossi et al. (2022, 2023 developed a set of portable sensor systems to evaluate the free acidity, the peroxide index and the total phenolic content of virgin olive oils. Lin et al. (2019) designed and developed a rapid-detection sensor for rice grain moisture based on Near-Infrared Spectroscopy (NIR). Khorramifar et al. (2021) designed an electronic nose, along with chemometrics methods, for fast, inexpensive, and non-destructive detection of different potato cultivars. Cui et al. (2019) presented an electronic nose system equipped with a sensitive sensor array for fast diagnosis of aphid infestation on greenhouse tomato plants at early stages. Grossi et al. (2019, 2022) proposed an innovative technique based on optical attenuation measurements to estimate the solid fat content in different vegetable oils and fats.

Among the different activities in a smart greenhouse, the determination of the ripening stage of fruits and vegetables is of primary importance to maximize crops production and minimize waste in both pre-harvest and post-harvest stage. Different techniques exist to provide an evaluation of the ripening stage (Rizzo et al., 2023). Standard techniques for ripening stage measurement include visual inspection, where the fruit skin colour is evaluated, and firmness monitoring, that can be carried out by hand or using a penetrometer. Such standard techniques are usually time-consuming, must be carried out by trained personnel and are prone to errors. Other popular techniques are the determination of total content of soluble solids (TSS) using a refractometer (Harrill, 1998) and gaseous ethylene measurement using porous ZnO nanosheets (Wang et al., 2019). More recently, innovative techniques have been proposed for ripeness stage determination using visible and near-infrared (NIR) spectroscopy (Munera et al., 2017) as well as set of sensors and data processing using artificial neural networks (Mazen and Nashat, 2019).

In this paper Electrical Impedance Spectroscopy (EIS) is investigated as a suitable technique to monitor the ripening stage of tomato fruits. Three different experimental setup are tested that are different in terms of type of measurement (destructive vs non destructive) and achieved accuracy. The results have shown how the ripening stage of tomato fruits can be evaluated using non destructive EIS measurements and can be easily implemented in a smart greenhouse or as a portable system.

2. Experimental measurement setup

The measurements carried out on tomato fruit samples are based on Electrical Impedance Spectroscopy (EIS) (Grossi and Riccò, 2017), a popular technique that has found applications in different fields, such as bacterial concentration detection (Grossi et al., 2019), corrosion rate measurement of metals in contact with an electrolyte (Feliu, 2020), human body fluid volumes measurements (Jaffrin and Morel, 2008), characterization of saline solutions (Grossi et al., 2019) and oil concentration measurements in metalworking fluids (Grossi and Riccò, 2017). In EIS measurements a sine-wave voltage test signal *V(t)* is applied to the sample under test (SUT) (Eq. 1):

$$V(t) = V_{DC} + V_{AC} \times \sin(2\pi f t) \quad (1)$$

where V_{DC} is the signal bias offset, V_{AC} is the AC amplitude, f is the frequency of the test signal and t is the time variable.

As a consequence of the application of the sinusoidal test signal, a current *I(t)* flows in the SUT (Eq. 2):

$$I(t) = I_{DC} + I_{AC} \times \sin(2\pi f t + \varphi) \quad (2)$$

where I_{DC} is the current bias offset, I_{AC} the current amplitude and φ the phase difference between the signals *V(t)* and *I(t)*.

The SUT impedance *Z* is a complex number defined as given by Eq. (3).

$$Z = \frac{V(j2\pi f)}{I(j2\pi f)} = \frac{V_{AC}}{I_{AC}} \times e^{-j\varphi} = \mathrm{Re}(Z) + j\,\mathrm{Im}(Z) \quad (3)$$

where $V(j2\pi f)$ and $I(j2\pi f)$ are the Steinmetz transforms of the time domain signals *V(t)* and *I(t)*.

In EIS the SUT impedance *Z* is measured on a range of frequencies and the measured spectra used to estimate the SUT parameter of interest. An experimental setup has been built using the impedance analyser Agilent E4980A, controlled by USB interface by means of ad hoc developed LabVIEW programs running on a laptop PC. Three different electrodes configurations have been tested, shown in Fig. 1 and hereafter referred as Setup A, Setup B and Setup C. Setup A is a non-destructive measurement configuration where two cylinder shaped stainless steel electrodes (diameter 6mm) are placed in direct contact of the tomato sample. Sample B is a non-destructive measurement configuration where a couple of adhesive commercial ECG electrodes, featuring high quality Ag/AgCl electrodes and high conductivity gel for optimal adhesion to the test surface, are applied to the tomato sample. Setup C is a destructive measurement configuration where two stainless steel needle electrodes (15mm length, spaced 20mm) are inserted inside the tomato sample. In all the three electrodes configurations the SUT impedance has been measured in the frequency range 20Hz – 2MHz with a sine-wave voltage stimulus of amplitude 100mV. The measured impedance spectrum has been represented using the Bode plots (*ReZ* and *ImZ* plotted vs the test frequency) and the Nyquist plot (*ImZ* plotted vs *ReZ* for the full investigated frequency range). The measured impedance spectrum has been also fitted to a suitable equivalent electrical circuit that models the system composed of the tomato sample and the electrodes.

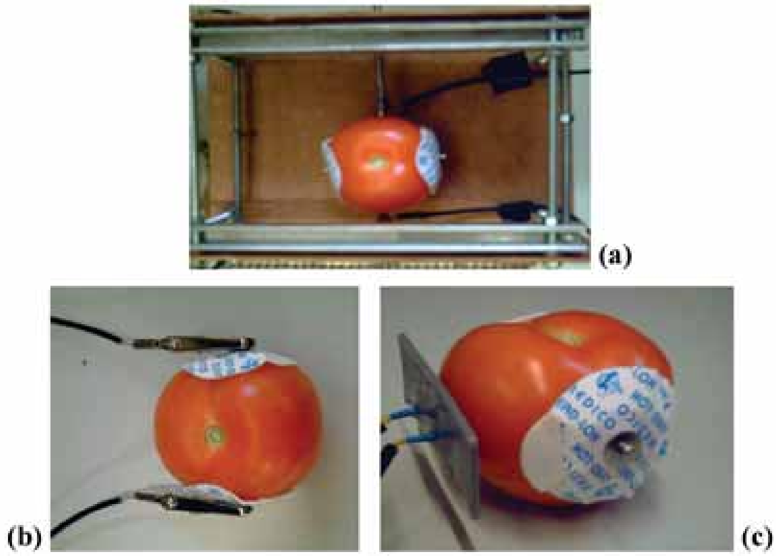

Fig. 1. The three different electrodes configurations tested for the analysis of tomato ripening

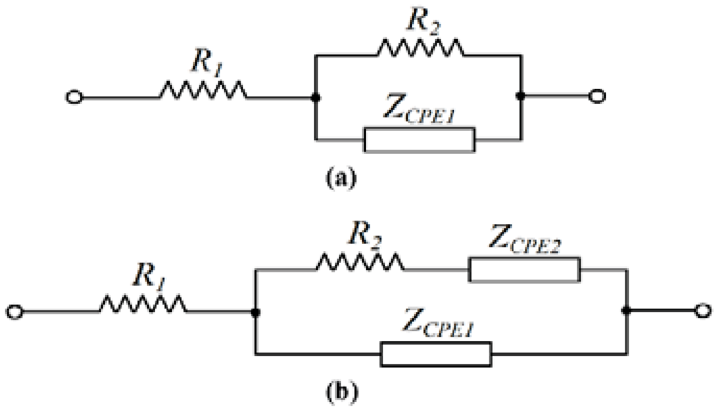

Fig. 2. Equivalent electrical circuit used to fit the impedance spectra measured using the electrodes configurations Setup A and Setup C (a) and Setup B (b)

Two different equivalent circuits, shown in Fig. 2 (a) and (b), have been considered, where Z_{CPE} represents a constant phase element, a component used to model non- ideal capacitive interfaces, which can be expressed by Eq. (4).

$$Z_{CPE} = \frac{1}{Q \times (j2\pi f)^{\alpha}} \qquad (4)$$

where Q represents the component capacitance while α accounts for the non-ideal electrode-sample interface.

The equivalent circuit of Fig. 2(a) has been used to model the impedance spectrum measured with Setup A and Setup C, while the equivalent circuit of Fig. 2 (b) for the impedance spectrum measured with Setup B. In the equivalent circuits, R_1 represents the parasitic electrical resistance of the electrode-sample interface, R_2 the electrical resistance of the tomato sample, Z_{CPE1} models the capacitive interface between the electrode and the tomato sample and Z_{CPE2}, present only in the impedance spectra acquired with Setup B, models the capacitive component due to the high conductivity gel. Data fitting to the measured impedance spectra has been carried out using the EIS Spectrum Analyser 1.0 (http://www.abc.chemistry.bsu.by/vi/analyser/). Both equivalent circuits provide a good fit for the measured data.

3. Results and discussion

Three tomato fruits from the same batch have been stored in a thermal incubator (WTC Binder) at 27°C and impedance measurements have been carried out at intervals of 1 day for a total of 7 days using the three different measurement setups presented in Section 2.

The impedance spectra at different measurement times are presented in Fig. 3 as Nyquist plots, where *Im(Z)* is plotted vs *Re(Z)* for the investigated frequency range. Measured data with Setup A, B and C are shown in Fig. 3(a), (b) and (c) respectively. As can be seen, in the Nyquist plots of the three measurement setups, a depressed semicircle (with the centre below the x-axis) is present that is due to the electrical resistance of the tomato sample (R_2) and the constant phase element that models the electrode-sample interface (Z_{CPE1}). In addition, in the case of experimental setup B, a straight line is present due to the high conductivity gel capacitance (Z_{CPE2}) that dominates the impedance spectrum at low frequencies. It can be observed that, in the case of Setup A, the measured impedance is not correlated with the ripening time, while in the case of Setup B and C a correlation can be observed with a decrease of the measured impedance with ripening time.

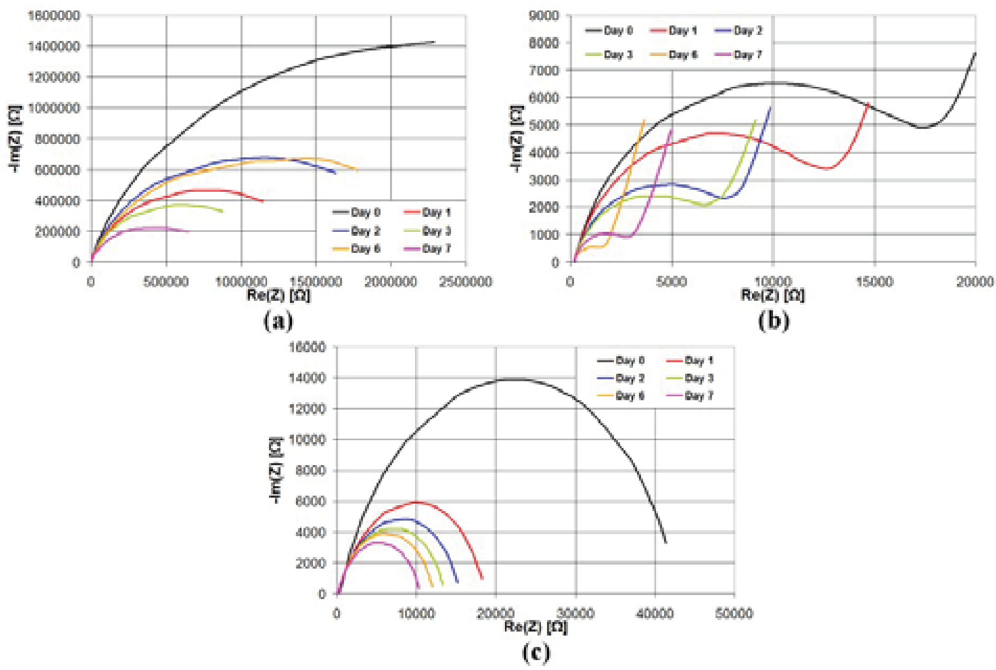

Fig. 3. Nyquist plots of the impedance spectra measured using the electrodes configurations Setup A (a), Setup B (b) and Setup C (c)

Table 1. Equivalent circuit parameters in the case of impedance measurements with Setup A

Time (days)	R_1 (Ω)	R_2 (Ω)	Q_1 (nF)	α_1
0	96.73	4183600	0.95	0.75
1	7.92	1488900	1.62	0.72
2	12.13	2123900	1.10	0.73
3	23.97	1164000	2.05	0.73
6	115.39	2320600	1.42	0.68
7	8.88	841970	4.27	0.65

Table 2. Equivalent circuit parameters in the case of impedance measurements with Setup B

Time (days)	R_1 (Ω)	R_2 (Ω)	Q_1 (nF)	α_1	Q_2 (μF)	α_2
0	151.71	18929	83.91	0.76	3.05	0.79
1	146.42	13520	98.51	0.76	4.15	0.77
2	143.13	8592	157.41	0.73	3.70	0.79
3	134.58	7527.4	179.54	0.72	4.99	0.74
6	167.23	1789.9	488.26	0.67	3.94	0.77
7	149.4	3154.9	247.18	0.70	5.00	0.74

Table 3. Equivalent circuit parameters in the case of impedance measurements with Setup C

Time (days)	R_1 (Ω)	R_2 (Ω)	Q_1 (nF)	α_1
0	35.53	43560	65.87	0.72
1	7.18	18947	110.64	0.70
2	21.34	15698	115.62	0.70
3	19.75	13758	115.59	0.70
6	27.60	12350	108.55	0.71
7	14.37	10597	122.74	0.70

The measured impedance spectra have been fitted to the equivalent electrical circuits of Fig. 2 (circuit of Fig. 2(a) for setup A and C and Fig. 2(b) for setup B) and the corresponding electrical parameters have been estimated and presented in Table 1 for setup A, Table 2 for Setup B and Table 3 for Setup C. In all cases the resistance R_1 does not feature significant correlation with the ripening time and this can be explained by the fact that this parameter models the parasitic resistance of the electrode-sample interface. In the case of Setup A, no electrical parameter presents correlation with the ripening time and this can be explained by the fact that that the surface contact between the sample and the electrodes generates high levels of noise that prevent accurate and reliable impedance measurements.

In the case of setup B the presence of the high conductivity gel at the electrodes-sample interface results in decreased values of the measured impedance with higher signal-to-noise ratio and more accurate impedance values. In this case, the resistance R_2 decreases with the ripening time (Fig. 4), while the capacitance Q_1 increases with the ripening time (Fig. 5) between the start of the measurements and day 6. During this period, R_2 presents an average decrease of 2.68 kΩ/day and Q_1 presents an average increase of 69.02 nF/day. Modelling the time variation of R_2 and Q_1 using a linear function results in a determination coefficient R^2 higher than 0.9. In the case of Setup C, only the resistance R_2 features a correlation with the ripening time. In this case, however, R_2 presents a strong decreases in the first day of measurements and then only marginal variations (Fig. 6). In particular, the average decrease of R_2 is 24.6 kΩ/day in the first day of measurements and 1.16 kΩ/day hereafter. This can be explained by the fact that Setup C (differently from Setup A and B) is characterized by destructive measurements and inserting the needle electrodes inside the sample produces significant alterations of the ripening process.

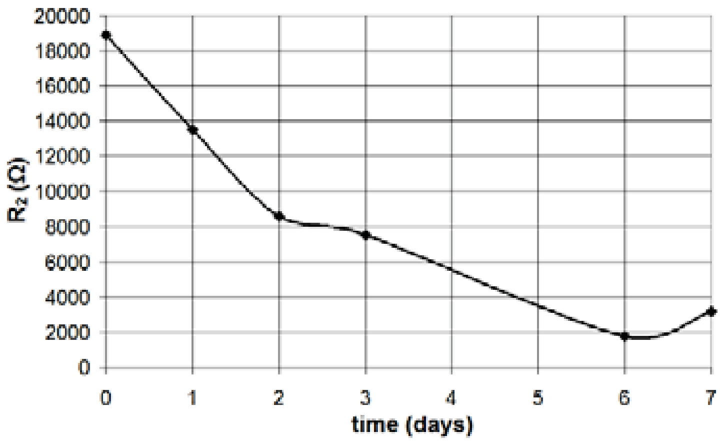

Fig. 4. Measured values of the resistance R_2 plotted vs. the ripening time in the case of Setup B

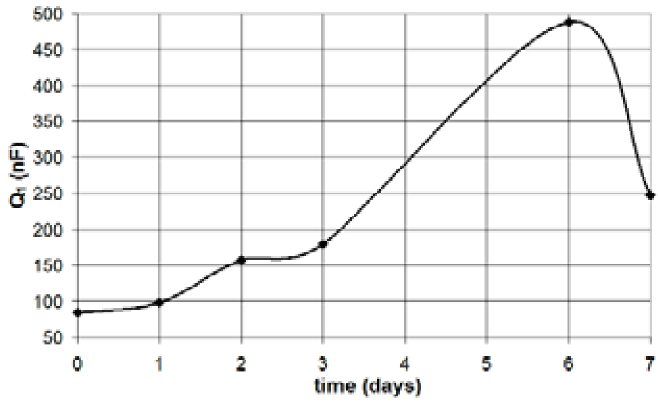

Fig. 5. Measured values of the capacitance Q_1 plotted vs. the ripening time in the case of Setup B

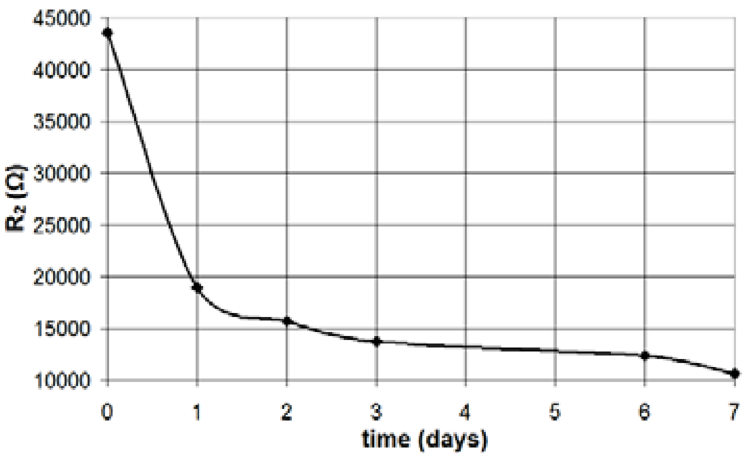

Fig. 6. Measured values of the resistance R_2 plotted vs the ripening time in the case of Setup C

4. Concluding remarks

The determination of the ripening stage of fruits and vegetables is of primary importance to maximize crops production and minimize waste in both pre-harvest and post-harvest stage. In this paper, Electrical Impedance Spectroscopy (EIS) has been tested as a suitable technique to evaluate the ripeness stage of tomato fruits. Three different measurement setups have been investigated, two featuring non-destructive tests and one featuring destructive test, with impedance measurements in the frequency range 20Hz – 2MHz in a temperature controlled environment (27°C) during 7 days.

The results have shown how destructive measurements (i.e. inserting the electrodes inside the sample) significantly alterate the dynamics of the ripening process and the measured impedance values. In the case of non-destructive measurements, instead, reliable data can be obtained by using a high conductivity gel between the electrodes and the sample under test. In the end, the proposed technique is very promising for smart evaluation of tomato fruit ripening stage in smart greenhouses.

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SYSTEMATIC STUDY OF EUROPEAN POLICIES IMPACTING ON EEE, BATTERIES AND THEIR END-OF-LIFE*

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Abstract

The European "*twin transition*" is based on products and technologies built with different materials such as critical raw materials (CRMs) that are mainly mined and refined outside the EU. Supporting and partially replacing the supply of these CRMs with secondary material from waste electrical and electronic equipment (WEEE) and waste batteries would reduce such dependency. The design, production and end-of-live management of these goods is regulated by several European policies. However, such large number of policies is not yet presented in an organized scheme that would support the producer and other stakeholders to fulfil their obligations. This work has the dual purpose: identify the European policies that impact on the entire life cycle of these two categories of products and provide a logical scheme of interconnection and dependence between the most relevant policies. After an initial phase of research and identification of the significant policies, an in-depth study of the policies of interest was conducted. Finally, the policies were organized in a scheme that defined hierarchies, connections, and dependencies between them. The study identifies 21 policies where the Green Deal and the Framework Directive are the main references. EEE and batteries productions are mainly influenced by the Circular Economy Action Plan, the Ecodesign Directive, and the REACH Regulation. EEE is also regulated by the WEEE and RoHS directives, while batteries by the Battery Regulation. This study can support producers and the other stakeholder involved in any part of the life cycle of EEE and batteries to identify the relevant and impacting policies.

Keywords: battery, critical raw materials (CRMs), electrical and electronic equipment (EEE), policy, rare earth elements

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1. Introduction

The European "twin transition", green and digital, is based on technologies and goods that require different materials for their production. In March 2023, the European Commission published the updated list of CRMs which are vital to produce these key technologies and equipment. The list consists of 34 elements including the “rare earth elements”, a group of 15 lanthanide plus scandium and yttrium. As many as 16 elements are also defined as “strategic raw materials” to implement the transition towards a European economy with a low environmental impact.

Critical raw materials are defined as such based on two parameters: the importance from an economic point of view and the risk of supply due to the concentration of supplies and the lack of valid substitutes (EC, 2023a). The final report on the CRMs confirms that China exercises a quasi-monopoly regime on almost all the elements of the list and in all stages of the supply chain (extraction, refining, transformation) (EC, 2023a). Supporting and partially replacing the supply of CRMs with their recovery from urban mining would reduce the environmental impacts caused by the extraction of raw materials. Furthermore, the valorisation of electrical and electronic waste (WEEE) and spent batteries would reduce the European dependence on third countries (such as China, the Democratic Republic of the Congo, Brazil, Russia) where the largest reserves are located (EC, 2023a). The recent proposal for a regulation on CRMs (CRM Act) fits into the perspective of guaranteeing a secure, diversified, economically accessible and sustainable supply of those materials (EC, 2023b). Furthermore, the regulations are becoming progressively more stringent and ambitious as demonstrated by the recent revision of some directives (Waste Framework, WEEE, RoHS) and the proposal to convert other directive into regulations (Ecodesign, Packaging, End-of-Life Vehicles).

Therefore, this work aims at identifying the most important European policies that impact on the production of electrical and electronic equipment (EEE) and batteries, and on their end-of-life management, and building a logical reference framework for market operators and other stakeholders. Particular attention will be paid to the role of producers, the subjects directly involved in from the design phase to the end-of-life phase.

2. Materials and methods

The study was built for progressive levels of analysis, increasing the degree of detail at each step. In the first phase, possible interesting policies were identified by a keyword search on the official website of the European Commission (https://commission.europa.eu/energy-climate-change-environment_en). In this phase, we collected the documents specific to the object of investigation and those potentially relevant proposed in the EC website. Some documents were rejected a priori as inconsistent with the topic despite being associated with a keyword. Table 1 shows the searched keywords with their respective total frequency, i.e., the total number of downloaded documents related to the keywords (which include, for example, proposed regulations, press releases, Q&As, attachments, etc.), and the specific frequency, i.e., only the most relevant documents that were investigated in the second phase and partially reported in Fig. 1.

In the second phase, the collected documents were analysed and organized by topic and according to chronology (WEEE, Batteries, CRMs and Ecodesign), removing policies that were not significant to the aim of the research. We organized the policies in tables according to the topics and we extrapolated the key information: title of the policy, date of publication, issuing body (European Commission, European Parliament, European Council), type of document (regulation, directive, press releases, factsheets, briefings, etc.). This step was fundamental to analyse and highlight the key documents. See Table 2 for the temporal organization of all the relevant policies.

In Table 3 we report the documents related to the topic “electrical and electronic equipment" and WEEE, as an example. Additional documents such as studies, reports, have been collected and categorized but are not listed in this table to keep it short.

In the third phase, the selected policies were organized in a hierarchical-relational level. In the first step, we analysed the overviews of the documents focusing on their relationship aspects, and we allocated in the scheme the policies that had a logical connection between them. The remaining policies were systematized in the scheme following a logical-deductive approach based on their topics, objectives and impacts generated by their adoption. In the last phase, our research was verified by comparing our results with those available in an international consultancy database which focuses on the EPR (Extended Producer Responsibility) aspect of the policies. SagisEPR (https://www.sagisepr.com) database summarizes and organizes the policies at a temporal and hierarchical level. The comparison with the content of this platform validated our research as the policies that we detected are also present in the database, an vice versa.

Table 1. Search keywords and frequency

Keywords	*Total frequency*	*Specific frequency*
Waste Framework	1	1
Circular Economy	1	1
(Waste) Electrical and Electronic Equipment (WEEE)	20	4
Batteries	28	4
Critical Raw Materials (CRMs)	24	2
Ecodesign and Ecolabel	24	3
Products	3	2
End-of-Life Vehicles	1	1
Right to repair	9	1
REACH and RoHS	6	2
Net Zero Industry	5	1
Due Diligence	5	1
Packaging	2	1
Semiconductor	8	1

Source: CE and our elaboration, years 1994 – 2023

Table 2. Temporal organization of policies

Title in short	*Publication*	*Source*	*Type of document*
Batteries and Waste Batteries	August 2023	The European Parliament and the Council	Regulation
New General Product	May 2023	The European Parliament and the Council	Regulation
Green Deal Industrial Plan for the Net-Zero Age	February 2023	European Commission	Communication
Net zero Industry	March 2023	European Commission	Act
CRMs	March 2023	European Commission	Act
REPowerEU Plan	May 2022	European Commission	Communication
Ecodesign and Energy Labelling Plan (2022-2024)	March 2022	European Commission	Communication

Fit for 55 - Climate Neutrality	July 2021	European Commission	Communication
Servers and data storage products, electric motors and variable speed drives, refrigerating appliances, light sources and separate control gears, electronic displays, household dishwashers, household washing machines and household washer-dryers and refrigerating	February 2021	European Commission	Regulation
A new Circular Economy Action Plan for a cleaner and more competitive Europe	March 2020	European Commission	Communication
The European Green Deal	December 2019	European Commission	Communication/ "road map"
Sale of Goods	May 2019	The European Parliament and the Council	Directive
Waste Framework	July 2018	The European Parliament and the Council	Directive
Packaging and Packaging Waste	May 2018	The European Parliament and the Council	Directive
RoHS	November 2017	The European Parliament and the Council	Directive
WEEE	July 2012	The European Parliament and the Council	Directive
Ecolabel	November 2009	The European Parliament and the Council	Regulation
Ecodesign	October 2009	The European Parliament and the Council	Directive
Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)	December 2006	The European Parliament and the Council	Regulation
End-of-life Vehicles	September 2000	The European Parliament and the Council	Directive

Source: CE and our elaboration, years 2000 – 2023

Table 3. Policies on EEE and WEEE

Title	*Publication*	*Source*	*Type of document*
Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)	July 2012	The European Parliament and the Council	Directive
Directive (EU) 2018/849 of the European Parliament and of the Council of 30 May 2018 amending Directives 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment	May 2018	The European Parliament and the Council	Directive
Commission implementing Regulation (EU) 2017/699 of 18 April 2017 establishing a common methodology for the calculation of the weight of electrical and electronic equipment (EEE) placed on the market of each Member State and a common methodology for the calculation of the quantity of waste electrical and electronic equipment (WEEE) generated by weight in each Member State	April 2017	European Commission	Regulation
Commission implementing Regulation (EU) 2019/290 of 19 February 2019 establishing the format for registration and reporting of producers of electrical and electronic equipment to the register	February 2019	European Commission	Regulation

Source: CE and our elaboration, years 2012 – 2019

3. Results and discussion

The study identified 21 relevant policies (19 in force and 2 under discussion), which directly or indirectly impact on electrical and electronic equipment (EEE), batteries and their end-of-life as reported in Figure 1. The diagram includes 2 packages of strategic initiatives (one of which from the United Nation), 5 plans, 5 regulations, 7 directives and 2 acts (those under discussion).

The lines connecting the policies have been drawn according to two criteria. The line with the double arrow highlights a mutual interdependence relationship between policies, while the line with the single arrow defines when one policy has a direct influence on another. The colour of the arrow determines which policy has the primary influence.

The analysis of the policy contents shows that they have an impact on one or more products, and they cover one or more aspects of the life of those products. Furthermore, all the "framework" regulations and directives are accompanied by various annexes and initiatives aimed at facilitating their adoption.

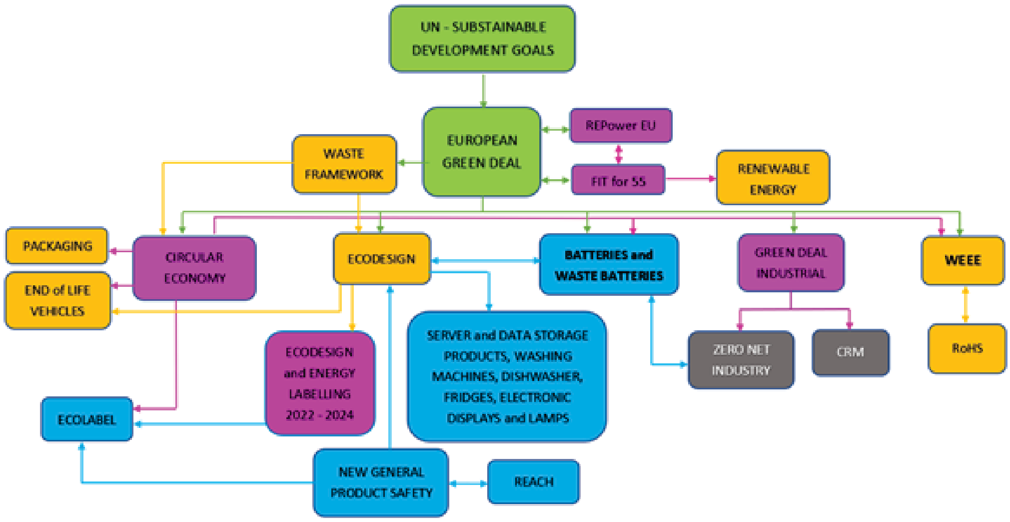

Fig. 1. Graphical diagram of policies that directly or indirectly impact on batteries and their end-of-life, Source: CE and our elaboration, years 2000 – 2023; Note: "strategic initiative packages" in green; "plans" in fuchsia; "directives" in yellow; "regulations" in blue; "acts under discussion" in grey.

The policies can be drawn from the broad and ambitious action program of the United Nations: the 2030 Agenda for sustainable development (UN, 2015). This strategic initiative defines 17 goals and 169 targets. Some of those targets are relevant to the present work: the 11.6 target on "Waste management" and several targets under the 12th goal of "Responsible consumption and production" (UN, 2015). Over the past thirty years, the European Union has issued various policies to provide the tools to achieve these objectives. From top to bottom, the second strategic initiative identified in Fig. 1 is the European Green Deal, a packet of initiatives to set the EU on the road to the green transition, with the final goal of achieving the climate neutrality by 2050 (EC, 2019). On the same level of importance, we set the "Waste Framework Directive": a key policy in the waste management and waste valorization based on the principle of "Extended Producer Responsibility" (EPR) (EC Directive, 2018a). The "REPower EU" is a plan that aims to diversify energy supply, accelerate the transition to clean energy and encourage energy saving (EC, 2022). The "Fit for 55 plan" is a set of proposals aimed at reviewing and updating EU regulations and implement new initiatives to ensure that EU policies are in line with climate objectives (EC, 2021). Directly linked to these plans is the "Renewable Energy Directive" which defines the regulatory framework for the development of renewable energies (pillars of the energy transition) in all sectors of the European economy and sets minimum targets to reduce the dependence on external suppliers (EC Directive, 2018b). For this reason, we place this directive il line with the "Fit of 55 plan" even if it is a pillar of the Green Deal.

At a subordinate level, there are those regulations defined as "pillars of the European Green Deal" (EC, 2019):

• the "Circular Economy Action Plan" which envisages 35 initiatives along the entire life cycle of the products. In particular, it focuses on the identification of 7 key product value chains for concrete actions (including "electronics and ICT" and "batteries and vehicles") and it focuses on strategic interventions across policies (EC, 2020);

• the "Batteries and Waste Batteries Regulation" updates the European framework for batteries to guarantee the sustainability and competitiveness of their value chains. This regulation introduces mandatory, sustainable, safety and labelling requirements for the marketing and commissioning of batteries, as well as for end-of-life management (EC, 2023c);

• the "Green Deal Industrial Plan" aims to strengthen the competitiveness of European industry and accelerate the transition towards climate neutrality. The plan is composed of four fundamental pillars, including the definition of a " predictable and simplified regulatory environment" to be achieved through the adoption of various initiatives. Two of these initiatives are under discussion: the "Net Zero Industry Act" and the "Critical Raw Materials Act" reported in the lower level of Fig. 1 (EC, 2023d).

At the same level of impact and importance are also set:

• the "Ecodesign Directive" which establishes a framework of mandatory ecological requirements for energy-using products (EC Directive, 2009);

• the "WEEE Directive" which establishes the rules for the treatment of electrical and electronic waste. The directive aims to contribute to sustainable production and consumption by preventing the creation of WEEE, by contributing to the effective use of resources and the recovery of raw materials through re-use, recycling and other forms of recovery, and by improving the environmental performance of all actors involved in the life cycle of EEE (EC Directive, 2012);

• the "End-of-Life Vehicles Directive" (EC Directive, 2000) and the "Packaging Directive" (EC Directive, 2018c), are of secondary importance for our goal but they are placed at the same level as the WEEE Directive because they are based on the same EPR principle.

At a next level, but closely related to the policies described so far, we find the "Ecolabel Regulation", the "Ecodesign and Energy Labeling Plan 2022 – 2024", the "Server and data storage products, washing machines, dishwashers, fridges, electronic displays and lamps Regulation" the "RoHS Directive", the "New General Product Safety Regulation", and the "REACH Regulation". The last two policies have a lower impact compared to the other ones.

The following paragraphs analyse the policies that have a direct impact on the producers of EEE and batteries and on these two products under investigation.

3.1. EEE and battery producers

Based on the study carried out by Ghoreishi and Ari (2019), the environmental impact of over 80% of the products is determined in the design phase. Moreover, the producers of EEE and batteries are one of the most important actors in the "twin transition". Indeed, with their design choices, such as the materials used in production, the manufacture phase, to the recyclability of waste products they have a strong impact in this transition. For these reasons several European policies, linked to the Green Deal, address the EEE and battery producers.

First of all, the Waste Framework Directive (WFD) has introduced the extended producer responsibility (EPR), a policy principle defined by Lindhqvist as "an environmental protection strategy to reach an environmental objective of a decreased total environmental impact from a product, by making the manufacturer of the product responsible for the entire life-cycle of the product especially for the take-back, recycling and final disposal of the product" (Lindhqvist, 1992). This principle is the at the heart of the WFD where in art. 8 specifies that to strengthen the hierarchy from prevention to recovery of waste the Member States may take legislative or non-legislative measures to ensure that any producer of the product has EPR (EC Directive, 2018a).

The other documents reported in Fig. 1 are in line to the WFD and they define other obligations on producers. The "Ecodesign Directive" sets obligations on producers so that environmental aspects are already taken into consideration during the design phase of products and there are more easily recyclable or disposable at the end of their life (EC Directive, 2009). The "Ecolabel Regulation" is voluntary system which defines the ecological quality label of a product. The regulation promotes products with a reduced environmental impact throughout their entire life cycle and provides accurate, non-misleading and scientifically based information on their environmental impacts (EC Regulation, 2010).

The introduction of the “Right to Repair Directive” would force manufacturers to ensure the availability of spare parts and information necessary to repair products, as well as provide information to the consumers on their right to repair. This obligation will be a turning point towards the realization of the principles of the circular economy (EC, 2023e).

Another not negligible directive affecting the EEE, and battery producers is the “Packaging Directive” that will be revised and published as a regulation. In fact, the packaging of sold products must comply with certain characteristics in terms of recyclability and reuse (EC Directive, 2018c). In line with the WFD, Member States should ensure the introduction of measures aimed at preventing the production of packaging waste and, in general, minimizing its environmental impact, as well as encouraging the introduction of the EPR. The “End-of-life vehicles Directive” is reported in the scheme as the waste batteries in the vehicles must be treated following the “minimum technical requirements” as reported in the Annex 1 of document (EC, 2020). This Directive is under revision.

3.2. Batteries

In this section we define the European policies that impact on the production, transport, distribution, and end-of-life management of batteries as one of the main products containing CRMs. These policies on a clockwise order are: the WEEE directives which impact on these products as batteries are often contained in EEE, the Zero Net Industry Plan, the CRM Act, the Circular Economy Action Plan, the Ecodesign Directive (soon to become a regulation), the REACH Regulation, the New General Product Safety Regulation, in addition to the main policy for this product which is the Batteries and Waste Batteries Regulation published in August 2023, which updates the Battery Directive. The scheme is shown in Fig. 2. The “Battery Regulation”, in the last approved version, has been extended to all categories of batteries including those incorporated into products. It has brought important updates in terms of requirements on producers who sells batteries on the European market, in terms of sustainability, safety, labelling and information provided to buyers. In addition, it defines the minimum requirements for extended producer responsibility, for the collection and treatment of waste generated by batteries. The Regulation imposes the "due diligence" requirements on actors operating on the European market and it defines several actions to reduce the negative effects of battery production and waste battery management (EC, 2023c).

The new regulation sets also minimum percentages for the collection of some elements (cobalt, lead, lithium, and nickel) and their use as recycled elements in the new products. This and other information will have to be provided by manufacturers, starting from 2026, through the introduction of the “battery passport”. This document should allow consumers to make more informed decisions and, once the composition of the batteries is known, to inform actors on the correct recovery and disposal operations to be performed on batteries (EC, 2023c). The objective of the European Commission is to progressively increase the recovered and recycled quantities of materials over the years as well as to make Europe increasingly independent from third countries for the supply of CRMs contained.

Lastly, the “REACH Regulation” has progressively reduced and banned the quantities of certain substances considered dangerous for humans and the environment by limiting their used in the products, including those addressed in our research (EC, 2006).

3.3. Electrical and Electronic Equipment (EEE)

The European policies that impact the production, transport, distribution, and end-of-life management of electrical and electronic equipment (EEE) are mainly the WEEE and RoHS Directive. Proceeding clockwise in Fig. 3, we list the Circular Economy Action Plan, the

Ecodesign Directive, the REACH Regulation, the Energy Efficiency Directive, the New General Product Safety Regulation and the CRM Act. All those policies have a direct or indirect impact on EEE producers, where the two most important legislations are the WEEE directive and the RoHS Directive.

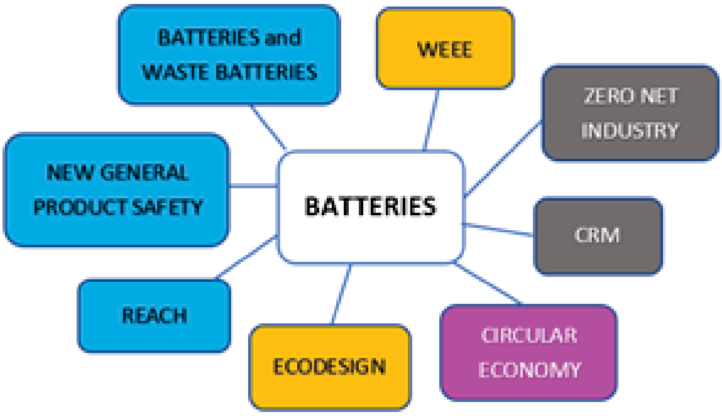

Fig. 2. Graphical diagram of the main policies that impact batteries; Source: CE and our elaboration, years 2006-2023

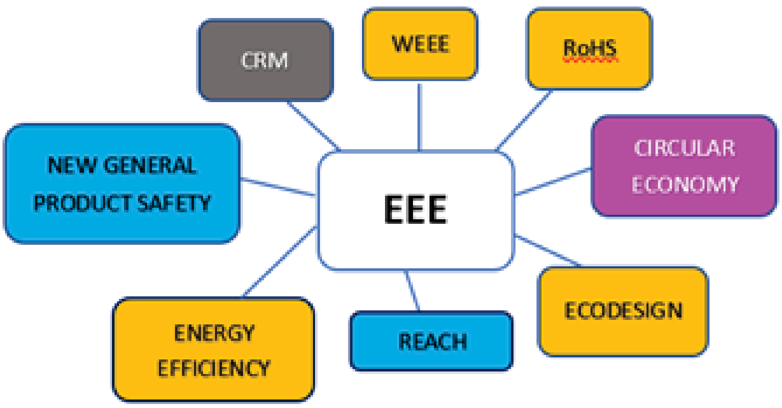

Fig. 3. Graphical diagram of the main policies that impact electrical and electronic equipment (EEE); Source: CE and our elaboration, years 2006-2023

The "WEEE Directive", in accordance with the upstream policies, establishes measures for the protection of human health and the environment, and the prevention of negative impacts throughout the entire life cycle of EEE. The legislation establishes the minimum percentages of recovery and preparation for reuse to be achieved, proportional to the weight of EEE placed on the market. However, there are currently no specific targets for the recovery of materials such as CRMs. A particularly relevant aspect underlined in the document is the importance of encouraging and activating cooperation circuits between all the actors in the supply chain to make actions more coordinated and, therefore, potentially more effective (EC Directive, 2012).

The "RoHS Directive", closely linked to the WEEE and Ecodesign Directives, is one of the most impactful policies for EEE producers as it limits the use of dangerous substances within these products to protect human health and the environment (EC Directive, 2017).

Following a stringent perspective on this topic, some products have been progressively banned such as fluorescent tubes containing mercury and halogen lamps.

4. Conclusions

The European "twin transition" need increasing quantity of raw materials including CRMs to manufacture technological equipment and products that reduce the environmental impact of our economy. The two most important product categories that contain these critical materials are batteries and electrical and electronic equipment (EEE). These products are influenced by various policies that have an impact on their design, production, use and end-of-life. To the best of our knowledge, these policies are not organized in a simple way for the operators, nor is there a reference scheme that presents all the relevant regulations for producers and other relevant actors. The lack of a clear systematization of documents that allows all stakeholders to easily identify objectives and targets to be pursued, from the prevention to recovery phase respecting the waste hierarchy, can be a "barrier to entry" in accessing the key information for the sector operators. The difficulty of accessing this information organised by topic and at a temporal level, limits the usability of the large amount of information produced at a European level amplifying the risk of getting non-compliant behaviour from operators. The present work attempts to fill this gap by identifying the European policies that impact on the entire life of these two product categories, as well as building a logical scheme of interconnection and dependency between policies.

In the first phase of the analysis, we observed that the policies have common and coherent objectives, they are consistent in the language and in addressing the actors of the supply chain. Each policy has also the positive aspect that, in the first part of the document, clarifies the subject of investigation and the goals to achieve. In terms of policy recommendation, we suggest the merge of some closely interconnected policies which would reduce their number as well as the substitution of policies that are no longer valid or only partially valid with the latest version in force. Additionally, we suggest the creation at European level of a single repository together with a summary document that contains the main information by topic.

Another difficulty we have identified for market operators is the different transposition of European directives in the 27 member states. Their implementation takes place at a national level and each country has a certain degree of freedom in defining the requirements, obligations, and responsibilities of the operators to achieve the required objectives within the established time framework. On the one hand, this favours some degree of freedom for the national policy makers that can take into consideration the technical and economic national resources. But, on the other hand, it adds elements of complexity especially for operators working in several European markets. From this point of view, the direction taken by the European Commission to transform directives into regulations will make it possible to set the same rules and requirements in all the Member states reducing the level of complexity.

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ENVIRONMENTAL EFFECTS OF THE 110% SUPERBONUS*

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Abstract

The Ecobonus is a state incentive dedicated exclusively to construction and plant engineering works designed to reduce the energy consumption of buildings with the implementation of renewable sources to the detriment of fossil fuels. It appears for the first time in the PNIEC (Integrated National Plan for the Economy and the Climate (PNIEC; 2020). This Plan establishes the objectives that the Italian government should achieve by 2030 regarding: energy efficiency; exploitation of renewable sources; reduction of CO_2 emissions.
This work, starting from the description of the Superbonus 110% (updated up to 31 December 2022), analyzes various aspects, especially highlighting the positive notes that its application brings to the environment. Finally, a case study is analyzed to highlight and quantify in detail the positive effects that this measure has on the environment.

Keywords: ecobonus, environmental impact, state incentive

1. Introduction

The climate is changing all over the world, atmospheric events have become devastating, extreme and causing considerable damage to the landscape and the surrounding environment. The causes of these phenomena are mainly attributable to two factors, both of an anthropic nature: human activities (agriculture, deforestation) and the combustion of fossil fuels (natural gas, oil, coal). Both contribute to the increase of the effect greenhouse. The concentration of greenhouse gases, especially carbon dioxide, has increased significantly, so much so that the decade from 2010 to 2019 was the warmest recorded to date

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(https://www.theguardian.com/us-news/2020/aug/12/hottest-decade-climate-crisis-2019).

According to ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development) estimates, CO_2 emissions from the Italian national energy system increased by over 8% in the first quarter of 2022 compared to a year earlier. Saving energy is one of the first steps to take in trying to mitigate climate change.

Precisely in this regard, the President of the European Commission, Ursula Von Der Leyen, announced in December 2019 the Plan of the "Green New Deal", whose objective is to make Europe the first continent with zero environmental impact by 2050 (European Council, 2019).

This Pact provides for the granting of financial concessions to support research and development projects to transform the building industry, favoring the construction of new residential buildings and the maintenance of existing ones with a view to energy saving.

It is in cities, where more than half of humanity now lives, that we will have to start consuming less polluting energy by building more efficient houses using eco-sustainable materials (Aabid and Baig, 2023) such as materials obtained from natural (De Luca et al., 2018a; Sangmesh et al., 2023) or recycled raw materials (Buonocore and De Luca, 2022), or with a degrading action of pollutants (De Luca et al., 2018b).

Italy has acted in this sense and one of the measures that characterized the Government's commitment was that of the Ecobonus.

In this work, a concise and general description of the ecobonus, implemented by the Italian government, is reported with particular reference to Superbons 110% (updated up to 31 December 2022), analyzing its fundamental characteristics and highlighting above all the positive notes that its application brings to the environment. Finally, a case study in the implementation phase is analyzed to highlight in detail the key principles of tax measures, with particular attention to environmental benefits.

2. Ecobonus

The Ecobonus is a state incentive dedicated exclusively to construction and plant engineering works designed to reduce the energy consumption of buildings with the implementation of renewable sources to the detriment of fossil fuels.

It appears for the first time in the PNIEC (Integrated National Plan for the Economy and the Climate) (PNIEC, 2020) published on 21 January 2020.

This Plan establishes the objectives that the Italian Government should achieve by 2030 regarding: energy efficiency; the exploitation of renewable sources; the reduction of CO_2 emissions. An excerpt of what can be read in the document regarding the position taken by Italy regarding sustainability states:

"This Plan intends to contribute to a broad transformation of the economy, in which decarbonisation, the circular economy, efficiency and the rational and equitable use of natural risers represent both objectives and tools for an economy that is more respectful of people and the environment", "Italy's goal is to contribute decisively to the realization of an important change in the energy and environmental policy of the European Union, through the identification of shared measures that are able to also accompany the transition underway in the manufacturing world towards the Green New Deal."

The objective of the Ecobonus is to fight climate change and at the same time be the driving force of national economic recovery, following the collapse caused by the COVID-19 emergency.

The reimbursement rates foreseen are:

• *50%* obtainable for purchase and installation of windows including fixtures and sunscreens, external doors, replacement of winter air conditioning systems with systems equipped with condensing boilers with efficiency at least equal to class A; replacement or new installation of winter air conditioning system equipped with biomass generators (e.g. pellets, chipboard).

• *65%* obtainable for a series of interventions, such as, for example, the replacement of winter air conditioning systems with systems equipped with condensing boilers with an efficiency at least equal to product class A and the simultaneous installation of advanced thermoregulation systems,

• *Superbonus 110%* summarized in the following paragraph.

3. Superbonus 110%

The Superbonus 110% was introduced by the "Relaunch" decree law of 19 May 2020, n.34 (Official Journal, 2020). From the point of view of the time frame, there are four changes to the Superbonus 110% made in 2020, six in 2021 and four in 2022. The current government has approved a new version of the Superbonus 110% starting from 1 January 2023. Despite the changes undergone, the Superbonus has nevertheless met with great success. This article takes into consideration the version of the Super bonus updated to 31 December 2022. The subsequent changes are above all of a financial nature with little influence on the purposes of this work which are precisely those of highlighting the positive effects of the Supebonus on environment. To obtain the Superbonus, the building must possess urban planning regularity. The fundamental requirement is that the works to be carried out guarantee the improvement of the building in question by at least two energy classes and the achievement of the minimum transmittance values defined by the minimum requirements decree.

The technician will then have to fill in the two energy performance certificates relating to the ante operam (before the intervention) and post operam (after the intervention) status. It is necessary to certify that the two energy classes are effectively increased with the consequent improvement in the values of the global non-renewable energy performance index, the renewable energy performance index and CO_2 emissions.

3.1. Driving and driven interventions

To benefit from the Superbonus, it is essential to carry out at least one driving intervention. The following interventions are defined as driving forces:

a) Thermal insulation of the building with a surface incidence greater than 25% of its total surface.

b) Replacement of the winter conditioning system (replacing the boiler alone is sufficient).

Once at least one of the driving interventions has been carried out, the beneficiary can take advantage of the possibility of carrying out the driving interventions, namely: the installation of photovoltaic systems; the installation of the thermal coat; replacement of fixtures; installation of columns for recharging electric vehicles; the elimination of architectural barriers for individuals with disabilities.

3.2. Characteristics of the materials to be used during the interventions

To take advantage of the Superbonus it is necessary to certify that the works are carried out with materials that meet the requirements of the CAM (Minimum Environmental Criteria) - Decree of 11 October 2017 (Official Journal, 2017). The decree provides that the products used comply with the emission limits and that they have a well-defined percentage of recycled material.

4. Case study

Below is reported a case study of a generic intervention on a property, in which the 110% Superbonus was used. The aim is to highlight, by way of example, what are the positive effects that the promotion of such state interventions can bring to environmental protection.

4.1. Brief description of the property intended for the intervention

The building under consideration is located in a municipality in Southern Italy. It has a reinforced concrete load-bearing structure and consists of a basement level with five floors above ground. The building falls within the climatic area classified as ZONE D and with degree-days equal to 1.586 (Table 1).

The building falls within the seismic area classified as ZONE 1, i.e., "Zone with high seismic hazard. Indicates the most dangerous area where very strong earthquakes can occur".

4.2. Description of the interventions

The execution of the planned interventions on the property are: Energy efficiency and seismic risk reduction.

4.2.1. Energy efficiency

One of the requirements to be able to access the Superbonus consists in the improvement of two classes as regards energy efficiency.

This was possible by intervening on the building envelope and replacing the heating systems. Thermal insulation of the vertical, horizontal and inclined opaque surfaces affecting the building envelope with an incidence of more than 25% of the gross dispersing surface of the entire building was provided.

In particular, the thermal insulation of vertical opaque surfaces concerns the external walls of the building. This will be achieved through the use of the external cladding system, i.e. the walls will be insulated by applying 12cm thick insulating panels on the external surface of the infill walls. The intervention will concern all the perimeter walls of the building present on each elevation with the exception of the basement. The insulation of the horizontal (attic) and inclined (roof attic) opaque surfaces will be achieved by applying a 12cm and 10cm insulating panel respectively.

4.2.2. Reduction of seismic risk

In summary, avoiding technical details, the interventions envisaged for the reduction of the seismic risk of the building, in application of the Superbonus, mainly concerned damaged and/or degraded structural parts and are necessary to improve their resistance and ductility characteristics. In addition, interventions have also been planned for parts that are not damaged in order to prevent local collapse mechanisms, as well as interventions for the solidification of infill walls (anti-rollover) through the application of fiberglass-reinforced cement mortar.

4.2.3. Additional or driven interventions

In accordance with the provisions of the Superbonus 110%, driven interventions have been envisaged, to be carried out jointly with the driving interventions listed above. The intervention includes:

The replacement of existing heat generators, with heating and domestic hot water supply systems consisting of CLASS A+ condensing boilers with solar integration.

New fixtures will be installed, and which will contribute to the energy efficiency of the building subject to interventio. They will have PVC profiles with a glazed surface consisting of double glazing with a gas cavity.

4.3. Environmental effects

The building under analysis before the intervention was characterized by an energy class E and had the following parameters:

- Non-renewable energy performance index= 161.06 kWh/m^2 year;
- Renewable energy performance index = 46.48 kWh/m^2 year;
- CO_2 emission= 30.12 kWh/m^2 year.

Everything is summarized in the APE (Energy performance certificate) prior to the intervention (Fig. 1).

After the intervention, the building is characterized by an energy class B and have the following parameters:

- Non-renewable energy performance index = 76.75 kWh/m^2 year;
- Renewable energy performance index = 0.52 kWh/m^2 year;
- CO_2 emission = 14.47 kWh/m^2 year.

Everything is summarized in the APE (Energy performance certificate) post-intervention (Fig. 2).

As can be easily seen from the comparison between the data before and after the intervention, the building will have a reduction in non-renewable energy performance of over 50%, a reduction in the renewable energy performance index of approximately 99% and a reduction in CO_2 emissions in atmosphere by more than 50%.

The above data demonstrate that energy efficiency interventions on buildings through the installation of a photovoltaic system, thermal insulation or through the replacement of fixtures bring benefits both of an economic nature with a reduction in consumption, and of an environmental nature with a reduction of CO_2 emissions into the atmosphere.

Table 1. Description of climatic zone D and degree days

Climatic zone D	***Switch-on period of the heating systems: from November 1st to April 15th (12 hours per day), unless extended by the Mayor.***
Degree-days	The degree-day of a location is the unit of measurement that estimates the energy demand necessary to maintain a comfortable climate in homes. It represents the sum, extended to all the days of a conventional annual heating period, of the average daily increases in temperatures necessary to reach the 20°C threshold. The higher the value, the greater the need to keep the heating system on.

4. Conclusion

Beyond considerations of a political nature, which are beyond the scope of this work, it is undoubtedly evident that promoting initiatives for the recovery and modernization of buildings is a fundamental contribution to safeguarding the environment and mitigating climate change.

In the case study presented, which represents one of the many possible interventions that can be implemented, we recorded a reduction in non-renewable energy performance by over 50%, a reduction in the renewable energy performance index by about 99%, and a reduction in CO_2 emissions into the atmosphere by over 50%.

Given the multitude of buildings in our cities that require energy redevelopment interventions, it is easily imaginable, based on our case study, the significant impact that widespread and comprehensive action would have, particularly in large cities that often represent critical environmental areas.

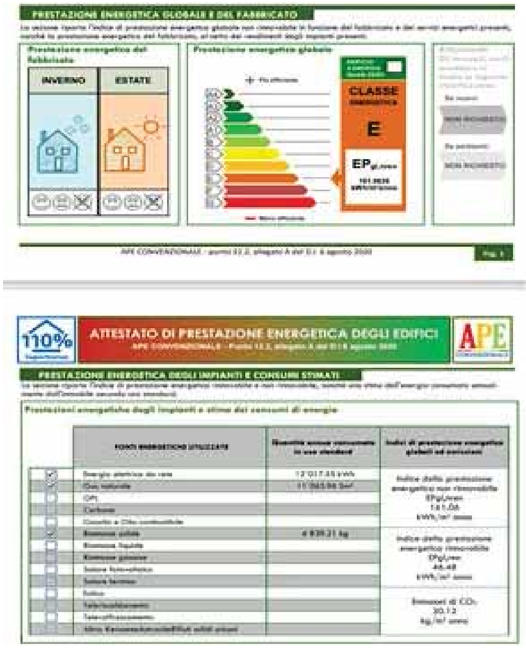

Fig. 1. Energy performance certificate (in Italian = APE) before the interventions

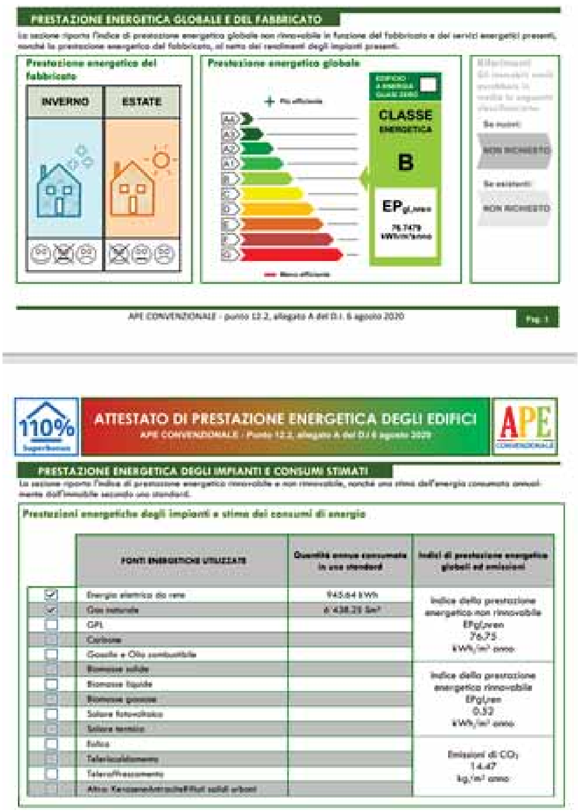

Fig. 2. Energy performance certificate (in Italian = APE) after the interventions

Subsidy measures must be embraced by the population and encouraged by governments to halt the negative climatic variations that are being recorded. The intelligent design of ecosystems, whether urban or otherwise, is essential to ensuring future generations have a healthier and more efficient environment than the current one.

Furthermore, the benefits of such initiatives extend beyond environmental impacts. Economic advantages include job creation in the green energy sector, reduced energy costs for building occupants, and enhanced property values. Social benefits, such as improved indoor air quality and overall well-being, further highlight the importance of these initiatives.

In conclusion, a concerted effort to modernize and recover our built environment is not only an environmental imperative but also an economic and social opportunity. By leveraging available subsidy measures and promoting sustainable design, we can create resilient urban ecosystems that contribute to the well-being of our planet and its inhabitants. The transformative potential of these initiatives is vast, and with collective action, we can ensure a sustainable and prosperous future for all.

Additionally, the success of such programs relies heavily on public awareness and education. Engaging communities through outreach and providing clear information about the benefits and processes of energy-efficient upgrades can foster widespread participation. This collaborative approach can accelerate the transition towards greener cities and more sustainable living practices.

Finally, continuous monitoring and evaluation of implemented projects are crucial. This ensures that goals are met and provides valuable data for improving future initiatives. By refining our strategies based on real-world outcomes, we can enhance the effectiveness of energy modernization efforts and maximize their positive impacts on the environment, economy, and society.

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FROM POST-CONSUMER PLASTIC TO ULTRA-RESISTANT URBAN LUMINAIRES*

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Abstract

The objective of this study is to produce urban lighting luminaires from recycled plastics, in order to reduce the volume of plastic waste and fight the unpleasant effects that salt and pollutants normally have on the classic metal lighting fixtures, thus finding a solution for a common problem in urban lighting by combining the virtuosity of circular economy with the elegant appearance of 100% Made in Italy luminaires.

After analyzing the corrosion process occurring in metals in marine environments, the research – conducted in cooperation with an external research organization – made it possible to develop an innovative manufacturing method (patent pending) allowing the manufacture of urban luminaires made from a specific virgin polyethylene compound that coats and agglomerates post-consumer polyethylene such as detergent bottles and disposable packaging.

In particular, the patent pending manufacturing method gives luminaires whose material appearance is similar to traditional metal luminaires, but immune to such problems as discoloration, corrosion and flaking of the paint, especially in marine environments. The patent pending luminaire thus consists of a removable LED lighting engine inside an extremely UV-resistant lighting body, which is externally coated with an innovative shield of 100% recyclable virgin polymers, giving the molded object considerable structural strength. In this way, the patent pending technology makes it possible to pursue the circular economy principle by implementing a set of actions to foster a transition from a linear to a circular economy system. The result is a sustainable production of durable luminaires characterized by a highly customizable design, a significantly lower environmental impact and a considerably extended useful service life if compared to traditional lighting fixtures.

Keywords: circular economy, recovered materials, recycled polymers, sustainability, urban lighting

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1. Introduction

The idea of producing urban luminaires from green materials, which are innovative for the sector, comes from the desire to apply the circular economy concept to outdoor lighting without leaving design and high quality standards in the background. The exponential growth in the production of disposable plastics and the consequent accumulation of plastic waste, which is often not properly disposed of, makes recycling the best way for us to reduce pollution and protect the environment by saving raw materials. The EU directives confirm this position, and since 2015, an action plan has been adopted aiming at fostering Europe's transition to a circular economy, which supports the value of recyclability and reuse of waste as raw material; in a perfect circle where nothing is thrown away and everything is reused (Chen et al., 2013; EC Directive, 2015).

This is the premise from which we started our research, which studied the best type of recycled plastic material to be used in the urban lighting sector in order to produce LED streetlights that are both environmentally friendly and resistant. A fundamental condition, given that luminaires are installed on public roads and under the action of atmospheric agents and pollutants (Xiaogai et al., 2011).

2. Material and methods

The main objective of this study is to manufacture durable and corrosion-resistant lighting bodies, with a highly customizable design, by combining the virtuosity of the circular economy principles with efficient Made in Italy luminaires. We started from analyzing the corrosion process on metals from which traditional outdoor luminaires are made from. This is a slow, yet unstoppable process whose extent depends on the physical properties of the liquid film formed on the surface of those metal structures exposed to atmosphere, and on those factors such as temperature, relative humidity and composition that frequently affect the corrosion process in a complex way and with antithetical effects.

Metals exposed to marine and industrial atmospheres do not corrode to negligible speeds like those exposed to moisture-free atmospheres. The strong contamination of chlorides and anthropogenic pollutants is the reason why metal bodies installed in these areas corrode rapidly. Therefore, the ISO 9223 standard divides the environments into different corrosion categories, according to the following parameters: temperature, relative humidity, deposition of sulfur dioxide and sodium chloride deposition. When exposed to aggressive environmental conditions – such as coastal or pollutants-rich environments – luminaires' frames are subject to corrosion under organic coating phenomena (delamination, blistering). This causes structural embrittlement and a change in their aspect, involving replacement costs and worsening of the related environmental footprint (Klevnäs and Enkvist, 2019).

The study conducted in cooperation with an external research organization made it possible to develop an innovative manufacturing technique (patent pending) allowing manufacturing urban luminaires from a specific compound of virgin polyethylene, which coats and agglomerates post-consumer polyethylene such as detergent bottles and disposable packaging, immune to corrosion. It consists of PSV (Plastic Second Life) certified polyethylene, which is endlessly recyclable, with 98% of post-consumer plastic content. The PSV certification issued by the Institute for the Promotion of Recycled Plastics (IPPR) is approved by the Circular Plastic Alliance (CPA) according to the UNI EN 15343 regulation.

The Circular Plastics Alliance aims to boost the EU market for recycled plastics to 10 million tons by 2025. The alliance covers the full plastics value chains and includes over 300 organizations representing industry, academia and public authorities (https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/circular-plastics-alliance_en).

The PSV label can be applied to recycled/regenerated material, semi-finished and finished products and it has different variants based on the material and on the intended use. It is required a minimum 30% of recycled material to obtain the PSV certification, whereas the under study urban luminaires are made of a post-consumer plastic content going from 50% for the monochromatic colors other than black, to 98% content for the monochromatic black color.

The texture of the multicolored urban luminaires derives from a PSV certified compound with a post-consumer plastic content equal to 75%, obtained from the combination of recycled polyethylene powders and shredded flakes and granules characterizing their "floral" finish.

(a) (b)

Fig. 1. Batch-dyed luminaires made from PSV certified polyethylene with even textures

(a) (b)

Fig. 2. Luminaires made from PSV certified polyethylene with the combination of recycled polyethylene powders and shredded flakes and granules

In both cases, the lighting body is anti-UV stabilized, anti-discoloration and 100% recyclable. To give an example of the amount of plastic used, if 10 bottles of plastic are used to make a chair seat and 25 kg of mixed plastics are used for a bench, to make a luminaire as the one shown in Fig. 2(b) you need 30 detergent bottles, thus creating elegant and one-of-a-kind designs.

2.1. Characteristics and advantages of the patent pending manufacturing technique

The recovery of disposable plastic packaging guarantees both circularity and lower environmental impact of the product, making it possible to produce durable and sustainable luminaires with the following characteristics:

- Infinitely recyclable: at the end of luminaires' service life, material can be recycled, with a 99,39% recycling rate, as documented and measured in the material balance assessment conducted on the luminaire model named "Olimpia".
- The re-use of both recovered materials and lighting body – in case of repair/ upgrading of their technological components – allows reducing the extraction of raw materials, thus saving about 15 kg of CO_2 for each avoided replacement (LCA study conducted in accordance with the requirements of ISO14040 and ISO14044 international standards).
- The 100% on site supply chain reduces the CO_2 emissions related to transport, thus solving the problem of finding materials.

The lighting bodies made from the selected polymeric materials are immune to corrosion, since they have no metal inside, which is one of the necessary components for corrosion to occur. In addition, they are impact and scratch resistant (with wall thicknesses greater than 5mm), because lighting fixtures' geometry – combined with thicknesses, mechanical properties and low-pressure production process – give the luminaires the highest protection rating against impacts (called IK), according to CEI EN 62262 (CEI 70-4) standard.

In this way, thanks to both innovative manufacturing technique (patent pending) and anti-UV and self-cleaning protective shield in 100% recyclable and PSV (Plastic Second Life) certified polymers, the material appearance of the luminaires is similar to the traditional metal ones, but with a significantly lower environmental impact than the latter. This is due to the considerably extended service life of these new fixtures, which are characterized by an impressive structural strength and immunity to (Mazzetto, 2013):

- Corrosion by atmospheric agents and pollutants, with no flaking or discoloration over time
- UV rays: no ageing or discoloration over time
- Mechanical impacts: highest protection rating against external mechanical impacts (IK10) and mechanical properties remaining unchanged from -76 °F to +176 °F (-60° C to +80° C), which guarantees body's useful service life longer than 50 years.

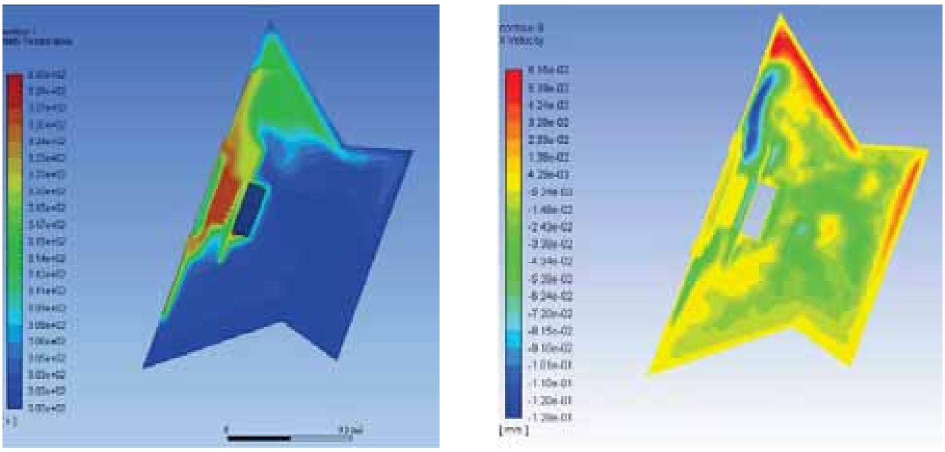
These luminaires can thus be defined as circular because, in addition to being sustainable in terms of materials and the entire manufacturing process, they can be recycled at the end of their service life through mechanical shredding, and be reused to manufacture new lighting fixtures respecting the sustainable principles of circular economy.

2.2. Calculation hypothesis

The aforementioned study made it possible to develop a parametric model allowing the optimization and validation of thicknesses, geometries, and thermo-mechanical performances of these polymer luminaires by means of both thermo-fluid dynamic and structural numerical analysis.

In particular, in order to analyze dissipative behavior of both luminaire and its subcomponents, it was developed a thermo-fluid dynamic calculation model based on the finite volume method. The thermo-fluid dynamic calculation model developed by this study allows solving the Navier-Stokes equations expressing mass, momentum and energy conservation for fluids in differential form. Concerning luminaire's system, the fluid has been represented by the air in its inside, which has a key role in heat dissipation, as it was also confirmed by the analysis performed. Instead, only the energy conservation equation was solved within the volume occupied by the solid components.

Moreover, thermo-fluid dynamic equations were coupled with a model for the calculation of the heat transmitted by radiation between the internal surfaces. A turbulence model was not included, because the analysis confirmed a low Reynolds number, and therefore the existence of an exclusively laminar fluid motion (Fig. 3). Starting from luminaire's thermal behavior, a study was carried out starting from the calibrated thermo-fluid dynamic model. Curves were finally drawn representing the minimum air volume that a PE lighting body should enclose according to luminaire's power rating, so that the temperature at LED's solder-point is lower than the acceptable limit. By means of these thermal tests, the maximum usable LED power within the polymeric lighting bodies was defined in order to guarantee a service life of the LEDs (L90B10) of more than 100.000 hours even in those environments with temperatures up to 45°C. Based on the results obtained by the thermo-fluid dynamic analysis, the geometry of the luminaires was then optimized from a structural point of view. The static analysis performed made it possible to develop luminaires models meeting the resistance checks with a wide margin of safety, and allowed the optimization of frames' thickness while respecting their geometries (Deodati et al., 2022).



(a) (b)

Fig. 3. Calibration model: temperature contour (K) on the left (a) and vertical speed contour (m/s) on the right (b)

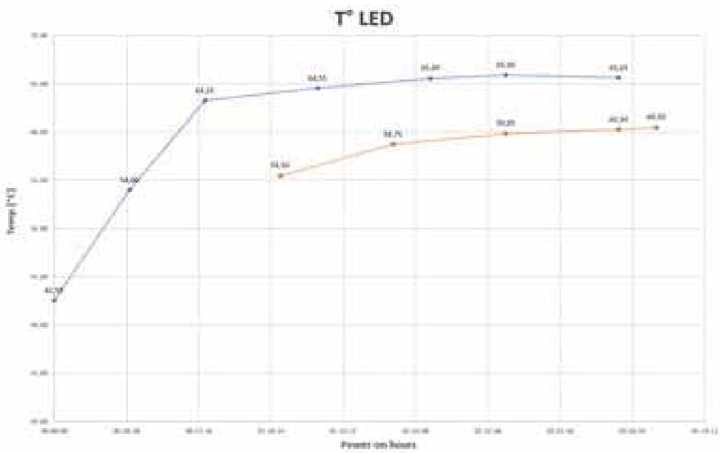


Fig. 4. Ts thermal test on LEDs (top line 70W, lower line 60W)

Projected L_{90}

	If = 50mA	If = 100mA
Ts = 55°C	-1,494,348	253,444
Ts = 85°C	200,452	115,531
Ts = 105°C	65,454	60,573

Fig. 5. Projected L90

2.3. The manufacturing technique

The study identified a sustainable plastics processing technology that is free of gases, annoying smells and toxic vapors and it is suitable for this kind of selected materials. This is rotational molding, also known as rotomolding, low-pressure and high-temperature plastics processing technology based on the adhesion of plastic materials to rotating hollow molds.

This technology allows manufacturing hollow objects with constant thicknesses and without welding spots. It makes also possible to produce large-dimensions products with very complicated contours, which are difficult to obtain with other molding techniques such as injection or thermoforming. This technique results to be particularly advantageous compared to others, not only because of the extreme ductility of the process, but also because molds have limited costs, which makes even small and exclusive production runs (even for dozen of produced pieces) economically viable. Thanks to rotomolding, it is possible to produce recessed objects with both complicated outlines and well-defined surfaces, and it is often possible to include metal inserts as integral parts of the product.

The machines consist of one to four carrier molds that, when heated, rotate at low speed around two rotation axes, allowing the polymeric material introduced in solid form – powder and possibly, also flakes – to adhere, once melted, to the walls of the mold in a homogeneous manner. Rotational molding is a manufacturing technique with a low environmental impact, as the melting of the powders occurs without direct contact with flames or heat sources. The machine heats the environment in which the mold is located, and the mold in turn heats and shapes the raw material contained in it by induction (Deodati and, 2022).

Research has thus shown that – by combining the potential of rotomolding technique with the flexibility of Plastic Second Life certified recycled polyethylene materials – it is possible to produce luminaires with the most different geometric shapes that result in being UV-resistant and therefore immune to those problems such as discoloration or paint delamination affecting the analogue luminaires made entirely of aluminum.

3. Results and discussions

From an environmental point of view, the patent pending manufacturing technology – which allows manufacturing urban lighting luminaires through an environmentally-friendly molding process and by using PSV (Plastic Second Life) certified and UV-stabilised polyethylene – fully complies with the circular economy principles because it:

- **Reduces** the use of new resources by using PSV-certified secondary raw materials.
- **Recovers** other manufacturers' waste (processing scraps and production waste) which becomes its raw material.
- **Repairs** the light source, thus extending luminaires' service life thanks to an easy replacement and upgrade of the led engine.
- **Recycles** the entire lighting fixture at the end of its service life.

• **Reuses** post-consumer plastic (up to 98% content) in each manufactured lighting body.

Luminaires have a service life greater than 50 years and a LED engine that can be easily and quickly replaced or upgraded at height by means of a patent pending maintenance system, thus guaranteeing an always standard-compliant and high-performance lighting inside a highly resistant and durable lighting body.

Compared to traditional aluminum fixtures, the flexibility obtained from the combination of the selected material and rotational molding, coupled with the high resistance of the lighting body, guarantees greater freedom for lighting designers in choosing luminaire's shape, with significantly lower costs than with aluminum die-casting (Piazza, 2013).

Since aesthetics has a key role for urban furniture, it is important for the design to meet both the aesthetical needs of the place where the luminaires have to be installed and the practical needs of the Municipalities requiring energy saving, durable lighting bodies and the least possible maintenance.

For example, the luminaire shown in the Fig. 1(b) – named Catullo – was designed by an architect for the Italian city of Sirmione (BS), which needed a luminaire with a minimal profile in order merge the tree-lined boulevard where it was to be installed (Fig. 7b).

To produce a similar luminaire in die-cast aluminum, it would have been necessary to use many molds, and to assemble the different final parts through bolted joints connections where, consequently, crevice corrosion phenomena may occur, since they represent critical points. Instead, with rotational molding, the molded object results in a single body produced with a single material, thus simplifying and speeding up the final assembly of the lighting body (Veronesi and Russo, 2003).

The patent pending manufacturing technique makes it possible to produce many different geometries, including by volumes' subtraction (Fig. 8b), since with rotomolding there are no problems related to undercuts, which are typical of those parts that cannot be molded in die-cast aluminum or plastic injection with a simple two-parts mold, because material would get stuck during the opening of the mold or during the expulsion of the molded piece (Veronesi and Russo, 2003).

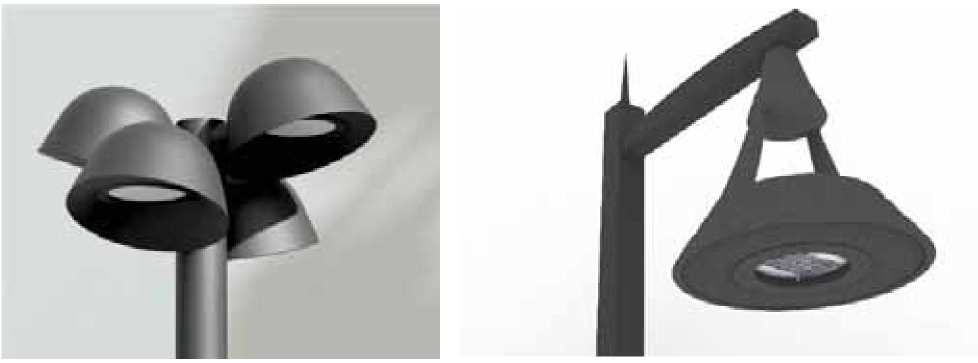
In addition, since this green material does not shield radio signals – as it occurs in aluminum lighting bodies – it is possible to keep luminaire's design unchanged by inserting into the lighting body antennas and remote-control devices (such as 5G technology), which are essential for the communication between people and devices in a future-oriented Smart City.

Polyethylene lighting bodies keep the advantages of the latest LED technology in terms of electric energy consumption and optic efficiency.

Fig. 6. Example of LED engine assembly/disassembly at height

(a) (b)

Fig. 7. Installation of polyethylene luminaires in the cities of Vieste (a) and Sirmione (b)



(a) (b)

Fig. 8. Example of different geometries obtainable from the combination of rotomolding and PSV-certified polyethylene

Table 1. Consumptions and annual savings of an installation with polyethylene LED luminaires

Compared parameters	***Units of measurement***	***Traditional luminaires***	***LED luminaires***
Luminaire's average lifetime (L90B10)	h	9.000	100.000
Number of luminaires	pcs	96	48
Total effective power	kW	16.50	3.12
Hour use per year	dd/yy	365	365
Electricity price	€/kWh	0.25	0.25
Average useful lifetime	yy	2.1	22.8
Annual electricity consumption	kWh/yy	72.270	13.665
Annual emissions of carbon dioxide	t/yy	46.97	8.88
Annual consumption tons of oil equivalent	toe/yy	6.21	1.17
Annual savings	%		81.0

Annual savings in electricity consumption	kWh/yy		58.605
Annual savings in electricity costs	€/yy		14.651
Annual savings in carbon dioxide emissions	t/yy		38.09
Annual savings of tons of oil equivalent	toe/yy		5.04

In Table 1, it is possible to compare the data concerning the project in Fig. 7(b) of 80 W - 24 pcs. of polyethylene LED luminaires illuminating a motor traffic road, and 50 W- 24 pcs. of polyethylene LED luminaires illuminating the sidewalks. This installation contributed to an annual savings of electricity costs amounting to €14.651 and to annual savings in carbon dioxide emissions of 38 t. The previous lighting system consisted in 24 poles with 125 W mercury vapor lamps – three for each pole – and one 250 W metal halide floodlight for each pole.

It should be noted that, apart from the huge energy savings, particular attention was focused on adapting lighting to standards and on achieving the best visual comfort by using 3.000 K color temperature LEDs with 80 minimum color rendering index (Deodati and Vendramin, 2022). The result of using the selected polymer are efficient LED luminaires ideal to be installed in marine environments or in those environments exposed to polluted agents, with resistant and sustainable lighting bodies having a service life longer than 50 years.

4. Conclusions

The aim of this study was to concentrate the best of research in sustainable materials and LED technology into a new way of conceiving light, particularly urban lighting. The corrosion resistance of polyethylene compared to metals used for traditional luminaires demonstrated how the recycling of plastic materials, which are often difficult to dispose of and polluting, can be beneficial in previously unconsidered sectors, such as public lighting.

This study highlights that polyethylene can be used to create urban luminaires that are not only sustainable and resistant to corrosion and scratches but also aesthetically pleasing and original, meeting the creative demands of the market. By integrating recycled plastics into urban lighting solutions, we can reduce waste and promote a circular economy, where materials are continuously reused and repurposed.

Moreover, the application of LED technology in these luminaires ensures high energy efficiency and long-lasting performance, further contributing to environmental sustainability. LED lights consume less power and have a longer lifespan compared to traditional lighting solutions, which reduces energy consumption and maintenance costs.

In conclusion, the innovative use of polyethylene and LED technology in urban lighting presents a promising pathway for enhancing sustainability in public infrastructure. By adopting such technologies, cities can improve their environmental footprint, lower operational costs, and provide visually appealing and durable lighting solutions that cater to modern urban design requirements. This approach not only addresses the issue of plastic waste but also sets a precedent for future research and development in sustainable urban infrastructure.

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REMOVAL OF NITRATES FROM DRINKING WATER USING CHIA SEEDS IN GAZA STRIP, PALESTINE*

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Abstract

This study aimed to measure the potential ability of Chia seeds Char for the removal of nitrate ions from water. The present work explores the unexploited property of chemically and thermally treated biomass-derived from chia seeds as new/innovative biosortive approaches as they represent widely available and are environment friendly to remove the key environmental pollutant of nitrate from drinking water. Different physical and chemical pre-treatments methods of the selected biomass (Chia seeds) to improve its performance in sorption ability to remove nitrate ions from drinking water was implemented and optimum bio-removal conditions of nitrate ions concerning the physicochemical influence of environmental parameters such as pH of the solution, biosorbent particle size, biosorbent dose, temperature, initial sorbate concentration and contact time were determined, in addition, the ability of regeneration and multiple uses of biosorbent material were conducted.

The results of this study showed that the highest efficiency of nitrate removal by Chia Char adsorbent was at pH using acetate and citrate acid solution, the particle size in the range (2 mm), burning temperature (650°C), room temperature of adsorbent/adsorbate mixture at (25°C) and the contact time of some hours. The results showed that the removal of nitrate increased with increasing the Chia Char dose. At the optimum conditions, the maximum amount of nitrate removed was by using (15 g) Chia Char. It was found that the Chia Char biosorbent could be recovered and reused for repeated procedures in removing the nitrate with an efficiency of (78%) in case of unwashed samples while the removal efficiency was (65%) in case of unwashed samples. The biosorbent was applied to remove nitrates in real drinking water samples in the Gaza Strip and the efficiency of nitrate removal was in the range (84 - 93%).

Keywords: char, chia, nitrate

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1. Introduction

One of the foremost dangerous problems with water contamination is that the nitrate anion. As a natural source, nitrate presents at moderate concentrations which resulted from the degradation of organic nitrogen-containing compounds. Their presence in nature was mostly in rocks, organic matter and soil. The presence of decaying organic matter deeply within the earth may be a polluting source of nitrates in nature (Hagerty and Taylor, 2012).

Human resource nitrate levels in groundwater kept on rise. The foremost explanation for such levels of nitrate is that the seriously utilize of fertilizers and pesticides also because the filtration of wastewater into the aquifer. Numerous variables can influence nitrate groundwater contamination levels, including fertilizers, fertilizer utilization rate, crop administration and therefore the kind of nitrogen utilized (Palestinian Water Authority, 2019). And also as a person's resources, chemicals introduced within the manufacture of explosives and unloading them as waste materials and also from sources cultivation of leguminous crops working on the stabilization of nitrogen within the atmosphere which rise nitrates concentration (Afkhami, 2003).

The negative activities that cause the degradation of water are often categorize into five types, like point contamination sources, diffuse contamination sources, groundwater over exploitation, artificial recharge and seawater intrusion (Martínez-Navarrete et al., 2011). Among them, diffuse contamination thanks to human activities may be a major explanation for pollution. Nitrate pollution of water thanks to intensive agricultural activities has become a serious environmental problem since 1970s. Nitrate is very soluble in water and doesn't readily bind to the soil causing it to be highly vulnerable to leaching. There are several potential sources of nitrate, including animal wastes, septic tanks, and municipal wastewater treatment systems and decaying plant debris. However, nitrogen enriched fertilizers for farming are considered because the main source of nitrate pollution within the environment. When nitrates form within the water at high concentrations, a phenomenon referred to as nutrients play a rapid role within the growth of algae in water, algae consume dissolved oxygen gas within the water, leading to the suffocation of fish and cause the death of fish (Ertaş and Öztürk, 2013; Köse; Melchert et al., 2007). Therefore, the magnitude of those health risks should concentrate to the physical body and protect it, noting that nitrates shouldn't exceed 50 mg/L in beverage, consistent with the planet Health Organization to guard human health from risk (WHO, 2018). It had been necessary to seek out solutions to deal with the danger of those nitrates. Many scientific researchers are conducted to treat the nitrate ion to supply an appropriate solution for these ions using inexpensive economical methods. New systems, like biological de-nitrification removal systems, are used as an example of anoxic microbial processes, which are used as how of handling the risks of this ion. This operation is performed can convert nitrate into nitrogen in four enzymatic steps via the subsequent intermediates: nitrite (NO^{2-}), oxide (NO) and dinitrogen oxide (N_2O) (Torrentó et al., 2010). The utility of those processes has been limited thanks to their expensive operation and subsequent disposal problem of the generated nitrate waste brine (Shrimali and Singh, 2001). this study aimed to research the efficiency of Chia seed for removal of nitrate from beverage by analyzing several parameters.

2. Methodology

2.1. Chia seeds biosorbent preparation

Preparation of Chia seeds bio sorbent was carried out at various main stages which include: collection from the relevant places, burning, washing thoroughly, air drying, grinding, sieving and finally drying in ovens at different temperatures. The prepared Chia seeds were stored in tight containers for the experimental testing of nitrate removal at various factors.

2.2. Collecting of chia seeds

Chia seeds were collected freshly from the distribution points of Chia local production factories.

2.3. Burning of chia seeds

After collecting Chia seeds, the Chia is placed in a crucible and then burned inside the oven at a temperature of 650 ° C for 30 minutes.

2.4. Chia seeds washing after burning

After washing the Chia seeds to ensure the removal of contaminants, Chia seeds were air dried for 12 hours at different temperatures (20 - 80 ° C) for 24 hours.

2.5. Chia seeds Sieving

After drying of the Chia seeds, the Chia seeds were grinded using pestle and mortar at suitable particle sizes. The grinded Chia seeds were sieved at different particle sizes using standard numbered sieves. Three types of particles with different size ranges were collected (coarse = 2.8 mm - 710 µm, medium = 710 µm – 90 µm and fine < 90 µm).

2.6. Chia seeds weighing

Samples of Chia seeds of different particle sizes were weighed at variable weights. The weights tested were 1g, 2g and 5g.

2.7. Preparation of nitrate solutions (adsorbate)

Stock nitrate solutions ($NO^{3-}aq$) (1000-1500 mg/L) were prepared using distilled water from a pure potassium nitrate in volumetric flasks and prevented from direct sunlight by covering with aluminum foils and stored in a refrigerator. Dilute solutions of the desired concentrations (50-1500 mg/L) were prepared in volumetric flasks by dilution using distilled water when required.

2.8. Preparation of acetate and citric solutions for pH control

Different pH values (3.5 – 10) were controlled using acetic acid (0.1 M) and citric acid.

3. Nitrate removal experiments by Chia seeds biossorbent by batch method

In the batch method a determined amount of Chia seeds biosorbent (adsorbent) of known particle size was mixed in a specific volume of nitrate solution (adsorbate) with a definite concentration. The mixture was kept at variable factors which discussed in the coming sections in order to examine their effect on the removal of nitrate from the lab prepared nitrate aqueous solutions and the natural ground water. After monitoring all factors, the optimum conditions for the highest rate removal of maximum nitrate amount were determined and controlled for further testing. These factors include: temperature of Chia burning, temperature of nitrate solution (adsorbate) during mixing with Chia seeds, contact time, particle size of Chia seeds adsorbent, nitrate concentration, pH value and the recovery of Chia seeds adsorbent. Each experiment was conducted in triplicate to obtain the mean value. Control experiments performed without addition of adsorbent` confirmed that self-degradation of nitrate was negligible. The amount of nitrate removed per unit Chia seeds adsorbent (mg nitrate per g adsorbent) was calculated at time *t* by Eq. (1) and at equilibrium by Eq. (2).

$$q_t = \frac{(C_i - C_t)V}{W} \quad (1)$$

$$q_e = \frac{(C_i - C_e)V}{W} \quad (2)$$

Where, qt and qe are the amount of nitrate removed in (mg/g) at time *t* and at equilibrium respectively; *Ci*, *Ct* and *Ce* are the nitrate concentrations at zero time, at time *t* and at equilibrium in (mg/L) respectively; *V* is the solution volume in (mL); and *W* is the sorbent dosage in (g).

The efficiency of nitrate removal at time *t* and at equilibrium respectively was determined using Eq. (3) and Eq. (4):

$$\%\ Removal\ at\ time\ t = \frac{(C_i - C_t)\ X\ 100}{C_i} \quad (3)$$

$$\%\ Removal\ at\ equilibrium = \frac{(C_i - C_e)\ X\ 100}{C_i} \quad (4)$$

3.1. Factors affecting absorption processes

3.1.1. Effect of contact time

The percentage of nitrate removal from aqueous solutions was determined by mixing a given amount of Chia seeds biosorbent (1 - 5 g) with 100 mL of 100 mg/L concentration of nitrate (NO_3-aq) solution using 100 mL Erlenmeyer flask at room temperature. Measurements of the amount of nitrate removed were carried out at different time intervals Hours and days. At each time, a definite volume of the solution was withdrawn by a micropipette and diluted with a suitable amount of distilled water to the linear range of nitrate calibration curve that based on five standard solutions of nitrate at the concentration range (5-20 mg/L). The diluted amount was filtered and the filtrate was analyzed for nitrate using spectrophotometer at solution at the characteristics wavelength (λmax = 220 nm). A controlled nitrate sample of (100 mL, 100 mg/L) without the addition of Chia seeds material was used as a blank. The removal efficiency was determined as % nitrate and as mg/g Chia seeds bio sorbent material.

3.1.2. Effect of oven temperature

The effect of Oven temperature of Chia seeds was examined at different temperatures (200, 350, 450, 550, 650 and 900 °C). The experiments were conducted at nitrate solution volume (100 mL), nitrate initial concentration (100 mg/L), and pH value (5.5-5.8). The amount of nitrate removed as % nitrate removal efficiency was determined at different time intervals within four days. The % of nitrate removed was determined versus different temperatures.

3.1.3. Effect of nitrate initial concentration

Different initial concentrations of nitrate aqueous solutions (50, 100, 250, 500, 1000 and 1500 mg/L) of a volume of 100 mL were mixed individually with a given amount of oven dried Chia seeds biosorbent (5 g) using 100 mL Erlenmeyer flask at room temperature. Measurements of the amount of nitrate removed were carried out at different time intervals. The amount of nitrate removed was determined versus concentration as mg/g Chia seeds biosorbent material.

3.1.4. Effect of particle size

The effect of adsorbent particle size on nitrate removal was studied preliminary using different particle sizes (coarse =2.8mm-710 μm , medium = 710 μm-90μm and fine < 90μm) by maintaining the pH (7-7.5), initial nitrate concentration (100 mg/L), volume of adsorbate (100 mL) and adsorbent dosage (5 g). The experiments were conducted at temperature of both the biosorbent and adsorbate solution at (20 °C) respectively. The amount of nitrate removed as % nitrate removal efficiency was determined at different time intervals within four days. Further experiments for examining the effect of particle size of the adsorbent were conducted by modification the conditions in order to improve the % removal efficiency of nitrate by the adsorbent.

3.1.5. Effect of adsorbent dose

The effect of adsorbent amount of adsorbent (dose) on nitrate removal was studied using different doses of Chia seeds adsorbent (1 and 10 5). The experiments were conducted at medium particle size of the adsorbent (710 μm-90μm), nitrate solution volume (100 mL), nitrate initial concentration (100 mg/L), and pH value (5.5-5.8). The amount of nitrate removed as % nitrate removal efficiency was determined at different time intervals within four days. The % of nitrate removed was determined versus adsorbent dose.

3.1.6. Effect of solution temperature

The effect of temperature of Chia seeds adsorbent mixed with nitrate solutions either Stock or ground water samples was examined at different temperatures (20, 40, 60, 80 and 100 ° C). The experiments were conducted at particle size of the adsorbent at (coarse =2.8mm-710 μm), nitrate solution volume (100 mL), nitrate initial concentration (100 mg/L), and pH value (5.5-5.8). The amount of nitrate removed as % nitrate removal efficiency was determined at different time intervals within four days. The % of nitrate removed was determined versus drying temperature.

3.1.7. Effect of pH

The effect of pH on amount of nitrate removal was analyzed over a pH range of (3.5-10.5). The pH was adjusted using 0.1N acetic acid and 0.1N sodium acetate solutions and measured by a pH meter (AD 1020). In this study, experiments were carried at medium particle size of the adsorbent (710 μm-90μm), nitrate solution volume (100 mL), nitrate initial concentration (100 mg/L), and the amount of adsorbent dose (5 g). The amount of nitrate removed as % nitrate removal efficiency was determined at different time intervals within four days. The % of nitrate removed was determined versus pH value.

Zyoud et al. (2015) studied removal of nitrate from aqueous solution via AC prepared from Olive Stones (OS) using conventional heating. They found that adsorption capacity increased at lower pH. It increased from 40% at pH 8 to 60% at pH 2.

3.2. Optimization conditions

After a number of testing experiments where the various factors were applied for the % removal of nitrate the researcher applied the best conditions that gave maximum removal of nitrate especially in real ground water samples. These factors include: amount of adsorbent dosage (5 g), pH (5.8), contact time (3 days), temperature (25ºC), particle size (2.8mm), Adsorbent temperature (20 ºC) and finally adsorbate temperature (25 ºC).

3.3. Applying the chia seeds biosorbent for nitrates removal from groundwater

After several developments and changing of factors to reach the best removal of synthetic nitrate solution. Real groundwater samples were tested for nitrate in Gaza Strip at the optimum conditions. A volume of 100 mL of the ground water was mixed with 5g of the

Chia seeds biosorbent the optimum factors were controlled. After 48 hours the amount of nitrate removed was determined. The test was repeated three times.

3.4. Recovery of chia seeds

The recovery procedure of Chia seeds biosobent after its use for nitrate removal was conducted by testing the Chia seeds material in a repeated experiment at the optimum conditions. Tests were carried out either after washing of the previously used material or without washing. Each experiment was carried out for 4 times at 48 hour intervals at each one.

4. Detection of NO_2- -N (Nitrogen, Nitrite)

In order to detect if any nitrate converted to nitrite during the removal of nitrate by the Chia seeds biosorbent, a nitrite test was conducted by the sulphanilamide spectrophotometric standard method (Michalski and Kurzyca, 2006). Reagent for nitrite analysis was prepared (Fig. 1). Phosphoric (50 mL, 85%) acid was dissolved in 200 mL water followed by 5g of sulfanilamide, then 0.5 g of N-(1-naphthyl) ethylenediamine was added to the mixture with stirring. the answer mixture was then completed to 500 mL by water.

Because of ion instability, the samples of nitrite should be analyzed immediately after collection. Nitrite sample (1 mL) was withdrawn using a micropipette then 1 mL of nitrite reagent was mixed for 1 minute until pink color appear. All samples were determined at wavelength 200-250 nm at spectrophotometer by applying calibration curve.

4.1. Detection of NH_3-N, (Nitrogen, Ammonia)

Ammonia is a species that could be produced as a side product during denitrification. Detection of ammonia was carried out by distillation and analyzed by titrimetric kjeldahl method. A sample (100 mL) was distilled and about 50 mL of distillate was collected into a solution of boric acid (20 mL) as absorbent solution. Few drops of bromocresol green and methyl red indicators mixture was added. The color changed from pink to green. The ammonia was determined by back titration using HCl (0.1 N) until green color disappeared. A blank sample was prepared. The volume of HCl consumed was determined and the amount of ammonia was calculated by the Eq. (5)

$$NH_3 - N\,\frac{mg}{l} = \frac{(T-B)\times N\times 17.004\times 1000}{C} \tag{5}$$

Where:
T = Volume of HCl solution consumed (mL) for sample
B = Volume of HCl solution consumed (mL) for blank
N = Normality of HCl
C = Sample volume

4.2. Result and discussion

4.2.1. Effect of pH on % nitrate removal by chia seeds char

Different pH values were used to examine the effect of pH on % nitrate removal by Chia seeds char. The various pH values (2, 4, 6, 8 and 10) were controlled using acetic acid and sodium hydroxide solution. The 100 mL of water solution of initial nitrate concentration 100 mg/L was mixed with 5 g Chia seeds char and the amount of nitrate removed was tested. The results are shown in Table 1 and Fig. 2. It is observed that the amount of nitrate removed increases with decreasing pH value and reaches the maximum at pH 4, 6 and 8 after 5 days contact time.

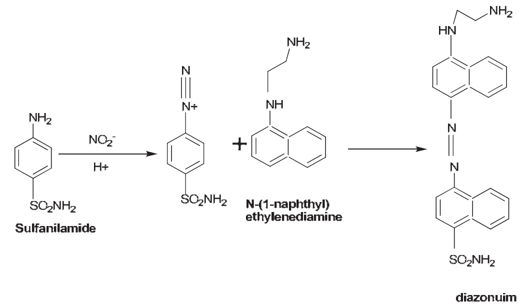

Fig. 1. Reagent for nitrite analysis

Table 1. Relationship between Chia seed mass (without treatment) and nitrate concentration in drinking water after 6 hours (initial nitrate concentration 29 mg/L)

Mass of sample "Chia" seed (g)	***Volume of tap water sample (mL)***	***Contact time (hrs.)***	***pH***	***TDS (µS/cm)***	***Concentration of NO_3^- (mg/L)***
1	100	1	7.11	1773	38
		2	7.36	1771	
		3	7.44	1783	
		4	7.08	1718	
		5	7.43	1716	
		6	7.18	1788	
2		1	7.04	1768	55
		2	7.28	1770	
		3	7.43	1780	
		4	7.22	1702	
		5	7.48	1707	
		6	7.2	1788	
3		1	6.99	1767	75
		2	7.25	1775	
		3	7.41	1766	
		4	7.05	1708	
		5	7.30	1699	
		6	7.08	1788	
4		1	7	1737	87
		2	7.18	1772	
		3	7.35	1774	
		4	7.04	1705	
		5	7.25	1702	
		6	7.03	1788	
5		1	7	1742	92
		2	7.17	1746	
		3	7.29	1782	
		4	6.99	1698	
		5	7.19	1678	
		6	7	1788	
Control	*Volume of tap water sample (mL)*	*Contact time (hrs.)*	*pH*	*TDS (µS/cm)*	*NO_3^- Conc. (mg/L)*
Without Chia seeds	100	1	7.47	1764	29

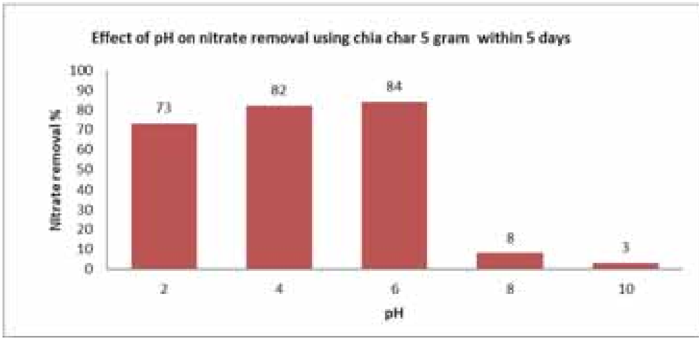

Fig. 2. Relation between pH and Chia seed after treatment as charcoal to nitrate removal in synthetic water, nitrate 100 mg/L)

4.2.2. Effect of Chia seeds char dose on % removal of nitrate

The effect of absorbent dose on the % efficiency of nitrate removal was studied. Different doses of chia char material were used (1-5 g) that of particle size (2mm). The nitrate solution (100 mL) was mixed with the chia seeds char for 5 days. Estimation of nitrate absorbed where conducted at different time periods. The results are shown in Fig. 3; it's observed that at the primary three days the half of nitrate removed increases with increasing of absorbent dose. Such a trend is usually attributed to a rise within the sportive area and therefore the availability of more active adsorption sites at higher amount of adsorbent (Kumar, et al., 2010). After five days equilibrium attained and nitrate removal is increase of the larger dose (86 for 5 g dose) comparing with both the smaller doses (79% for both 3-4g doses) which attributed to the supply of the low doses to soak up more nitrate at while. As Table 2 and Fig. 3.

4.2.3. Comparison between chia char with citric 0.2M and acetic acid 0.2 M for nitrate removal from synthetic water 100mg/L Nitrate (days)

In this experiment, a sample of chia 5 g added with 2 mL of acetic acid was compared with another sample of chia 5 g with 2 mL of citric acid in 100 mL of synthetic water 100 mg/L nitrate, these experiments were conducted for each sample at pH 5.8, 25 ° C for 5 days, the result showed that the best removal was with citric acid more than acetic acid where nitrate removal percent with citric acid was96% but 72% with acetic acid, this refer to the best removal with citric acid as Table 3 and Fig. 4.

4.2.4. Effect of particle size of Chia char on % of nitrate removal

The particle size is an important parameter owing to its effect on % removal efficiency and on the amount of nitrate adsorbed per unit weight of chia char the percentage of nitrate removal from aqueous solution by chia char was examined using 5 g of the chia char at different particle sizes (2mm, 1.18 mm, 600 μm and 425 μm). The pH was controlled at 5.8. The nitrate solution (100 mL, 100 ppm) was mixed with the chia char and the amount of nitrate removed was determined. The results are shown in Table 4 and Fig. 5 It is observed that the amount of nitrate removed increases with 2 mm of particle sizes and reaches the minimum range at 425 particle sizes.

4.2.5. Chia char recovery

Exhausted Chia char was re-tested for nitrate removal at the optimum conditions with or without reconditioning. Four cycles measurements tested chia char with and without washing by distilled water. The cycles were repeated for four cycles and tested for (3 to 5 days) to check the recovery activity of the adsorbate. The results are given in Figs. 6-7 we observed that the Chia char preserved its activity toward the removing of nitrate from water samples. The results show that the removal efficiency is 78-75% in case of unwashed samples while the removal efficiency is 21-28% in case of washed samples. This attributed of the presence of acetic or citric acids that sustained it is activity onto the chia char adsorbate.

5. Optimum conditions of chia char for the % removal efficiency of nitrate

The improvement of the efficiency of the Chia char for removing nitrate from aqueous solutions from the previous results could be summarized in the steps reported in Table 5.

Table 2. Relation between chia seed char dosage (g), heating temperature and nitrate concentration

Mass of chia seeds (g)	*Volume of water sample of (100 mg/L NO_3^-)*	*Contact time (h)*	*pH*	*Temp. (^oC)*	*NO_3^- conc. (mg/L)*
2	100	12	7.5	150	100
				250	99
				350	98
				450	98
				550	98
				650	97
				750	97
				850	98
3				150	100
				250	99
				350	98
				450	98
				550	90
				650	88
				750	88
				850	90
4				150	100
				250	99
				350	98
				450	92
				550	81
				650	74
				750	76
				850	86
5				150	100

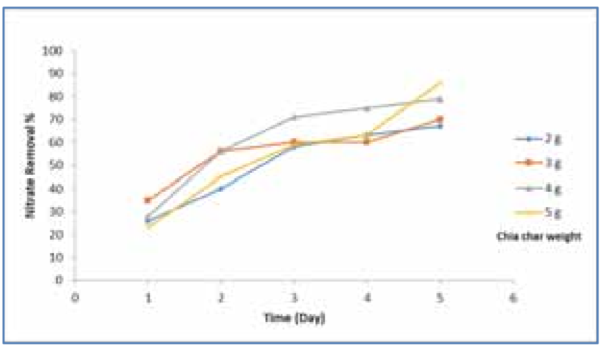

Fig. 3. Relation between chia seeds char dosage (g) and nitrate percent removal with 2 mL acetic acid

Table 3. Comparison between chia char with acetic acid and citric acid for nitrate removal

Mass of sample "chia" char	*Volume of synthetic water sample of (100 mg/L NO_3-)*	*Contact time (day)*	*pH*	*NO_3- Conc. (mg/L)*
Acetic Acid (2 mL of 0.2M)				
5 g	100 mL	1	5.8	80
		2		72
		3		44
		4		39
		5		28
Citric Acid (2 mL of 0.2M)				
5 g	100 mL	1	5.8	70
		2		63
		3		40
		4		32
		5		10

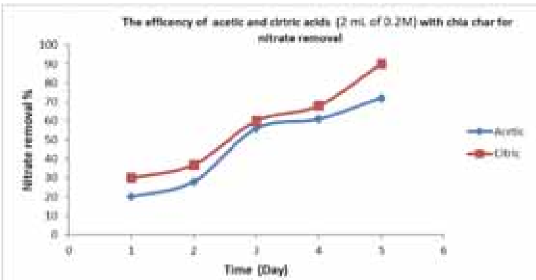

Fig. 4. Comparison between chia char (5g) with addition of 2 mL of 0.2 M citric and acetic acid on nitrate removal

Table 4. Effect of particle size of chia char on nitrate removal

Mass of sample "chia" seed	*Mesh size*	*Volume of synthetic water sample of (100 mg/L NO_3^-)*	*Contact time (days)*	*pH*	*NO_3- Conc. (mg/L)*
5 g	2 mm	100 mL	1	5.8	66
			2		58
			3		42
			4		31
			5		17
	1.18 mm	100 mL	1		90
			2		86
			3		78
			4		75
			5		70
	600 µm	100 mL	1		100
			2		95
			3		87
			4		89
			5		81
	425 µm	100 mL	1		100
			2		98
			3		96
			4		94
			5		89

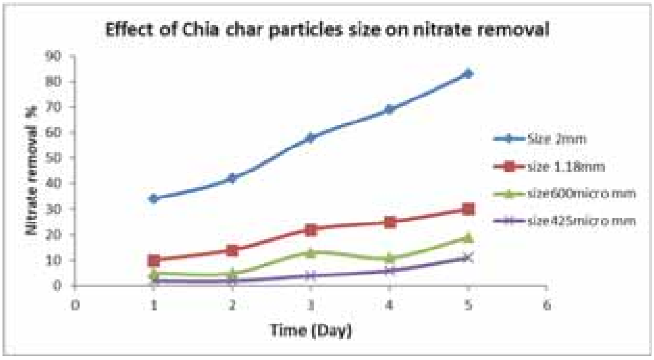

Fig .5. Effect of particle size of chia char on % of nitrate removal

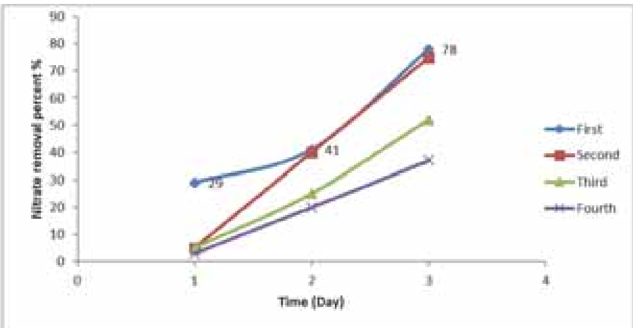

Fig. 6. Chia recycling without washing in other synthetic water sample 100 mg/L

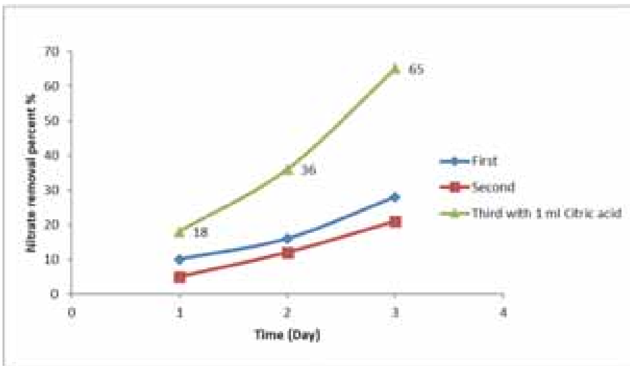

Fig. 7. Chia recycling with washing in other synthetic water sample 100ppm

Table 5. Optimum conditions of chia char for the % removal efficiency of nitrate

1	Dose	5g and greater
2	pH	5.8 – 6.0
3	Time	5 days
4	Oven temperature (Burning)	650 -750 ^oC
5	Temperature	25 ^oC
6	Particle size	2 mm
7	Removal of Nitrate %	90 %

6. Conclusion

This study investigated the adsorption capacity of Chia seeds char as a potential adsorbent for the removal of nitrate from aqueous solutions using batch system. The experimental parameters were very important in order to understand the mechanism of adsorption of nitrate ions, such as pretreatment methods of biosorbent, the initial nitrate ion concentration, adsorbent dose, pH, and particle size. The results showed that:

1. Chia char was an effective biosorbent for nitrate removal comparing with other reported adsorbents.
2. Nitrate in synthetic and real groundwater could be effectively reduced by the Chia Char biosorbent process with a nitrate removal rate of about 93%.
3. The results showed that the removal efficiency of nitrate related to particle size and the best particle size was of 2 mm of raw Chia char.
4. Experimental data showed that nitrate adsorption increased by decreasing pH value of the solution and the optimum pH was at (5.8-6).
5. The results showed that equilibrium time for nitrate removal was after 5 days.
6. The removal efficiency increases with increasing biosorbent dose.
7. For recovery Chia char biosorbent, the results showed that the removal efficiency is 65% in case of washed samples while the removal efficiency is 78% in case of unwashed samples.
8. The results showed the efficiency removal of the use of Chai char in the process of treatment of nitrate ion in real samples was between (78-93%).
9. Through comparisons between chemical and thermal treatment of chia, it was found that heat treatment has a much better effect than chemical treatment of chia on nitrate removal, since thermal burning at a temperature of 650 ^{o}C gave better results than burning using chemical acids and bases.

7. Recommendations

Although the strategy used in this work has given very promising results, there are number of areas that need further investigation. These include:

1. Further testing Chia Char biosorbent for other un-studied pollutants in water and groundwater should be conducted.
2. More analysis is recommended for the water quality after treatment with the Chia Char biosorbent. Thus further researches on other pollutants using this technology will not only improve its efficiency, but also develop new modeling techniques.
3. More study on the economic feasibility of the Chia seed biosorbent preparation.
4. Further research investigation to promote a large-scale utilization of neglected natural resource for water treatment through filtration is needed.
5. Using natural media for water treatment applications are strongly recommended due to their local availability, an environmentally friendly, and cost-effectiveness.
6. Investigation of using different forms of filter modifications by using another form of media toward the enhancing of the water treatment efficiency and speed up the removal process
7. Further study and research should be carried out on the development of water filters to improve upon its performance in water treatment by the government, nongovernmental and private sector to make it available in most homes thereby alleviating the issue of inadequate supply of safe water in our local area.
8. Besides these, some other issues, such as assessment of efficacy of sorbents for NO_3^- removal under multi-component pollutants, investigation of these materials with more real water samples under different concentration and TDS, and continuous flow studies should be

conducted in detail.

Last but not the least; it would be worthwhile to investigate the reusability of the spent adsorbents as only a few studies are available in literature. More research is needed in the field of regeneration and finally for the environmentally safe disposal of NO_3- laden adsorbents.

Symbols and abbreviations

AC	Activated carbon
BAT	Best available technology
°C	Celsius
Conc.	Concentration
CAC	Commercial activated carbon
CMWU	Coastal municipality water utility
DW	Distilled Water
ED	Electric dialysis
EPA	US Environmental Protection Agency
g	Grams
GDDI	Growing degree days
Hrs.	Hour
IUPAC	International union of pure and applied chemistry
M	Molarity
MPa	Mega pascal pressure unit
mg	Milligram
mm	Milliliter
mg/L	Milligram per Liter
nm	Nanometer
μm	Micrometer
pH	Acidity or Alkalinity of an aqueous solution
ppm	Part per million

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DEVICE CONCEPT TO DETECT MICROPLASTICS IN WATER*

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Abstract

Here a continuous measurement concept for detecting the type and amount of individual microplastics in water was investigated. The optical NIR spectroscopy was applied. Data analysis of the NIR spectra was performed using the Support Vector Machine (SVM) method. The device concept was able to distinguish between microplastic sample materials passing through the cuvette tube with water. The tested plastics were PE, PVC, PA, PC, PP and PU. The intended use of the device concept was to monitor treated effluent before it is discharged back into the water body.

Keywords: device, microplastics, NIR, spectroscopy, SVM

1. Introduction

Plastics have been produced worldwide due to their wide usability, durability, and ease of manufacture (Kutz, 2011). Plastics are also a problem (Andrady, 2017; Vethaak and Legler, 2021), since once released into environment, plastics typically just break down into smaller pieces, making them an environmental issue. The harmfulness of microplastics is partly due from the used chemicals in the manufacturing process of plastics that enhance their properties (softness, UV resistance, flame retardancy etc.). On the other hand, microplastics can act as carrier for a wide range of other substances like other chemicals, hormones, and microbes. Microplastics are generated from plastic products, packaging material, car tyres, and fabrics. Over time, microplastics end up everywhere – including in water bodies (Hänninen et al., 2021).

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In environmental science, microplastic samples are collected from a place of interest in a measurement campaign. The types and quantities of collected microplastic samples are analyzed in a sophisticated laboratory. Thus, it can take several weeks from sample collection to results. In contrast, in water utilities and industry, there is a need for continuous and real-time monitoring of microplastics to optimize the process, energy efficiency, and the amount of chemicals used. However, adequate equipment is not available. Therefore, there is a need to develop a practical method and a device for various applications.

Here a continuous measurement concept for detecting the type and amount of individual microplastics in water was investigated. In the device concept microplastic sample materials were passing through the cuvette tube with water. The optical NIR spectroscopy was applied. Data analysis of the NIR spectra was performed using the Support Vector Machine (SVM). The tested plastics were PE, PVC, PA, PC, PP and PU. The intended use of the concept is to monitor treated effluent in the future.

2. Measurement setup

The measurement concept was designed to study the optical NIR spectral response of microplastics in water. The optical setup was built around a glass cuvette in which the microplastics traveled with the water flow. The water flow was produced by a pump. Two light sources were used. The laser diode of 450 nm was used to detect individual microplastic particles. Once the particle was detected, the broadband Xenon flash lamp (190-1100 nm) was used to illuminate the target particle for spectral analysis. These light sources were aligned along the same optical path. Data acquisition of the NIR spectra was performed using the computer system controlled by the LabVIEW software.

2.1. Setup

Fig. 1 presents the measurement system in more details. Table 1 presents the description of components. The variable speed pump sucked up water-microplastics-mixture from a glass bowl via the silicone tube. In the middle of the silicone tube, the 120 mm long glass cuvette (OD 5.2 mm / ID 1.2 mm) was installed (X axis). The beam of the laser diode LD was guided via the beam splitter BS-1 and the lens L2 to illuminate the cuvette perpendicularly (Y axis). These axes formed the X-Y plane that was 100 mm above the optical plate.

On the opposite side of the cuvette was the lens L3 and the receiver detector Dblock to observe laser-illuminated particles at the cuvette measurement point. The optical path of this receiver was set at an angle of few degrees to avoid the saturation of the receiver channel.

Once a particle was observed at the cuvette, the 5 mW Hamamatsu Xenon flash lamp XFL was triggered. The produced light was conducted via the optical cable OF-1 to the convex mirror CM1 to produce the collimated light beam. This beam was further guided via the cylinder lens L1 to form the defined optical beam having limited diameter of few millimeters. This beam has same alignment as the laser diode beam after the beam splitter BS-1.

The primary interest was the scattered light from microplastics illuminated by the Xenon flash lamp. To receive this scattered light at the NIR (near infrared) wavelength range, the lens L4 and the convex mirror CM2 were placed on the X-Z plane tilted 30 degrees from the Z axis. The optical fiber OF-2 guided light to the Oceans NIR Quest+ spectrometer NIR-S having the measurement band of 900–1700 nm.

The system was computer controlled using the LabView software. One measured spectrum contained 200 consecutive flashes of the Xenon flash lamp. The integration time of the spectrometer was 5 seconds. The NIR spectrometer was connected directly via the USB while other controls were interfaced via the data acquisition card DAQ.

2.2. Sample production

For the experiments, microplastics were produced by milling high quality engineering bulk plastics on an automatic milling machine. The produced plastic chips were sorted mechanically with metal meshes. The types of plastic milled were polyvinylchloride, polyamide, polycarponate, polypropylene, and polyurethane. Also, polyethylene particles with fluorescence coating were used. Table 2 shows the types and sizes of microplastics tested. In the visible light range, the microplastics used were translucent or colored.

The microplastics were mixed with de-ionised water. To minimize particle clustering, the water-microplastic mixture was continuously stirred during the measurement. This also assisted the lighter microplastics than water or heavier microplastics than water to mix throughout the liquid volume and to enter to the sampling system.

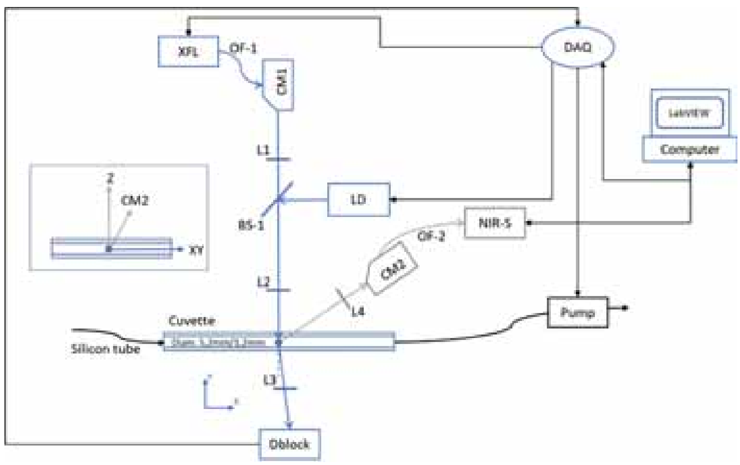

Fig. 1. The diagram of the optical measurement setup

Table 1. Description of the components used in the measurement set-up

Component	***Description***	***Component***	***Description***
XFL	Xenon Flash Lamp	LD	Laser Diode
OF-1, OF-2	Optical Fiber	Dblock	Detector
CM1, CM2	Convex Mirror	NIR-S	NIR Spectrometer
L1, L2, L3, L4	Lens	DAQ	Data acquisition card
BS-1	Beam Splitter	Pump	Variable Speed Pump

Table 2. The microplastic samples

	Plastics		***Color***	***Size range [mm]***	***Density [km/m³]***
1	PE-1	Polyethylene	Red	180–212	910–967
2	PE-2	Polyethylene	Green	125–150	910–967
3	PVC	Polyvinyl chloride	Transl.	250–500	1380
4	PA	Polyamide	Transl.	125–250	1090–1140
5	PC	Polycarbonate	Transl.	125–250	1210
6	PP	Polypropylene	Transl.	250–500	895–920
7	PU	Polyurethane	Blue	250–500	48–961

3. Results

The microplastics in water were measured in the glass cuvette tube. The microplastics were classified based on their NIR spectral data by using support vector machine (SVM) models. The implementation of the SVM model was accomplished in the Matlab by the PLS toolbox of Eigenvector Research, Inc. Basically the SVM separates data points into two classes by defining a high dimensional support vector between the two groups utilizing the features measured from each data point.

In plastic particles, typical complex features of NIR spectra requires complex model for non-linear separation in which supervised SVM model with appropriately selected parameters succeeded well. The spectral data of all microplastic particles were classified using the SVM classification models specific for each type of microplastic. In other words, the classification was performed independently 7 different times.

In the Fig. 2, all 2300 microplastics in each sub-diagram are colored in type order (PE-1, PE-2, PVC, PA, PC, PP, and PU). The vertical axis describes class the prediction probability of the particle of each type. In the leftmost diagram, using the SVM classification model for PE-1 microplastics, the classified PE-1 microplastic particles are at the top, while all other microplastics (PE-2, PVC, PA, PC, PP and PU) are at the bottom. The analysis showed that each individual PE-1 particle distinguished by a clear margin from the other types of microplastics. Equally well separated the PE-2 microplastic particles (2nd left diagram) and the PVC microplastic particles (3rd left diagram) from the other microplastics in their own analysis.

The specific SVM model for the PA microplastic particles (middle diagram) worked well, although it had some cross correlation sensitivity to the spectral components of the PU microplastics as well. Similar good behavior was found for the specific SVM model for the PC microplastic particles (3rd from right diagram), which had some cross correlation sensitivity to the spectral components of the PP microplastics.

Even though the specific SVM model for the PP microplastic particles (2nd right diagram) worked, it also had cross correlation sensitivity to the spectral components of the PU microplastics. When the class prediction probability value of the classification was set to 0.70, the class error for the PP microplastic particles was 0,048. Similarly, the specific SVM model for the PU microplastic particles (rightmost diagram) worked, but it also had cross correlation sensitivity to the spectral components of PP microplastics and to some extent to PA microplastics. The class error for the PU particles was 0.061.

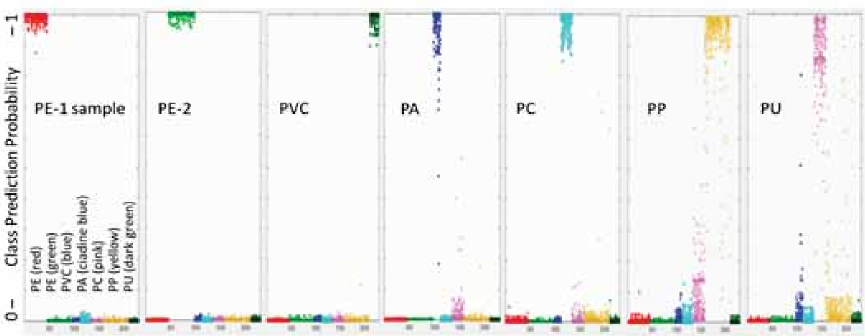

Fig. 2. Class prediction probability of the microplastics; all microplastics have been tested against each microplastic type specific SVM model; the leftmost diagram presents the separation of the PE-1 microplastics from other microplastics types, when the PE-1 specific model was utilized; respectively, the other 6 diagrams present the separation with other microplastic specific SVM models

4. Discussion

The device concept developed shows that microplastics can be distinguished even when measured in a water-filled cuvette. The analysis shows that the polyurethane (PU) microplastics were challenging because they share some common spectral characteristics with the polyamide (PA) microplastics and especially the polypropylene (PP) microplastics.

In addition to pure spectral separation method, the distinction between the microplastics could also be exclusionary in a certain order. For example, it seemed that the polyamide (PA) microplastics specific SVM model might separate the polyamide (PA) microplastics from the polyurethane (PU) microplastics better than using the polyurethane (PU) microplastics specific SVM model to separate the polyurethane (PU) microplastics from the polyamide (PA) microplastics.

From a device development point of view, it would be worthwhile to increase the Signal-to-Noise-Ratio (SNR) of the measurement system to reduce the measurement time. It would also be useful to consider whether the optical bandwidth of the measurement system could be increased to allow, for example, the detection of organic objects or other type of particles.

To compensate for the limited light output of the Xenon flash lamp used, the pump was stopped for the duration of the measurement and a sufficient integration time was applied. During the stopped flow, some particles moved vertically up or down depending on its density. Future development steps could include the extension of the optical bandwidth, the improvement of the SNR, and better control of particles in the flow. It is also worth noting that the produced microplastic type specific SVM models are specific to this setup. Thus, the classification models need to be re-generated for each device revision.

From the process management and environmental requirement perspectives, it is mandatory to monitor water quality in both water utilities and water-intensive industries. To optimize the process, energy efficiency, and the amount of chemicals used, there is also a need for continuous and real-time monitoring of microplastics. However, currently adequate on-line monitoring equipment are not available. The instrument development is a long-term effort, and it requires new instrument concepts, innovations, and continuous testing to ensure sufficient measurement capability and to gain user acceptance. Once this is achieved, the same measurement approach can be utilized for various applications. In this development, the primary target application was to monitor treated effluent or to monitor other water intensive processes of circular economy in the future.

5. Conclusions

This study investigated the concept of continuous measurement to detect and identify individual microplastics in water. The optical measurement was carried out in a glass cuvette. The microplastics tested were polyethylene (PE), polyvinylchloride (PVC), polyamide (PA), polycarponate (PC), polypropylene (PP) and polyurethane (PU). The identification method used was based on NIR spectroscopy. The data analysis of the NIR spectra was performed using the Support Vector Machine (SVM), where the microplastics were classified by the SVM models. Each SVM model was able to classify one type of microplastics from other types of microplastics.

The device concept was able to identify microplastics from water in a glass cuvette. However, some of the SVM models also had cross correlation sensitivity for other types of microplastics. From SVM model point of view, the polyurethane seemed to be the most troublesome type of microplastics studied. The minimum and maximum class error was 0 and 0.064, respectively, with a class prediction probability of 0.70.

Acknowledgements
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MICROPLASTICS GENERATION DURING AN ICE HOCKEY GAME*

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Abstract

Here the generation of microplastics during an ice hockey game was studied. There is a general need to understand the amount and type of microplastics produced and where microplastics can end up. The study has analyzed airborne heavier plastic particles landed on the ice. The study identified 12 different types of microplastics. Of all particles, 61% were PIR (polyisoprene rubber) and PE (polyethylene) particles. One ice hockey game was estimated to produce about 20 g of microplastics. The microplastics mainly ended up in ice discharge or use sites and in the general wastewater system with the ice washing water.

Keywords: environmental load, microplastics, sport

1. Introduction

Plastics are used worldwide due to their wide usability, durability, and ease of manufacture. The technical properties of plastics, such as density, strength, insulation, etc., can be tailored as needed as part of the plastics manufacturing process (Kutz, 2011). Plastics are also a problem, as plastics are typically non-degradable. Plastics just slowly break down into smaller and smaller pieces, making them an environmental problem (Andrady, 2017; Vethaak and Legler, 2021; Salthammer, 2022). Over time, microplastics end up everywhere. Microplastics are pieces of plastic smaller than 5 mm in size. Micro-rubbers are a sub-category of microplastics. The smallest microplastics can also turn into airborne dust and become inhalable (Andersson-Sköld et al., 2020; Chen et al., 2020; Periyasamy and Tehrani-Bagha, 2022).

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Ice hockey is an example of a sport where microplastics are generated from the use of protective gears and other equipment. During an intense game, players' ventilation and heart rate are at a high level. This might allow microplastics to enter the players' respiratory tract as they breathe.

In this work, awareness of this sport related topic was increased. The amount and type of micro-plastics generated during an ice hockey game has been investigated by studying the microplastics that landed on the ice. The study focused on 12 different types of microplastics. The aim was to identify the most common types of microplastics. The aim was also to provide an estimate of the weight of microplastics generated during one ice hockey game. Further, it was discussed to where microplastics might ended up.

2. Case

In this case study, samples were collected from Kajaani ice hall on March 3rd 2023 from the 3rd period of a televised ice hockey match between Hokki (Finland) and HK Zemgale (Latvia). In terms of game events, the hockey game in question can be considered as normal. Ice and water samples were taken from the 3rd period, because after the last period the Zamboni machine's tanks could be emptied without any hurry.

As an initial preparation, after the ice maintenance at the end of the 2nd period, the Olympia ICEBEAR Electric Zamboni was cleaned. In practice, all collected ice was removed from the machine, and then the ice storage tank, i.e. the snow bucket, was rinsed clean with hot water. The ice wash water tank was also emptied, rinsed, and filled with hot tap water. The freezing water tank was also filled with hot tap water. In addition, the coarse mechanical filter of the circulated wash water was drained and rinsed clean. Finally, the Zamboni machine was inspected visually to be clean. During commercial breaks for televised hockey games, most of the loose ice was picked up with shovels from the goal and the blue line (bench) areas and was then thrown away. The amount of this loose ice collected was assumed to be insignificant for this study.

Ice maintenance after 3rd period was carried out in accordance with the normal process for the entire ice area. The Zamboni machine 1) brushes and peels off a layer of ice about 1 mm thick and collects the loose ice in a snow bucket, 2) washes the ice with washing water and recirculates the washing water through a coarse filter back into the washing tank, and 3) spreads the freezing water on the ice with a spatula. The ice handling width of an ice machine is 2.13 m (in practice the full width of the machine). The washing water tank has a capacity of 204 litres and the freezing water tank has a capacity of 838 litres. The snow bucket has a capacity of 2.9 m^3.

After the ice maintenance, the snow bucket was emptied outdoors on top of an unused and clean film (LDPE, 0.2 mm thick, 3x5 m^2). The color of the used film was blue. All the loose and peeled ice collected (almost1 m^3) was shoveled to the trailer with aluminum shovels at -10 °C. In preparation, the trailer was washed and waterproofed with a similar blue LDPE film. Finally, the ice on the trailer was transferred to a warm hall to melt.

The water from the washing tank was drained through the self-designed filter unit and the liquid flow meter (SMC LFE1C4F1, 0.5-20 L/min) into the drain. The filter unit had two steel mesh filters: 315 μm and 100 μm. The flow rate was initially 7 L/min, but it slowed down towards the end to 2 L/min due to the accumulation of solid particles on the filters. At the end of the water drainage phase, a small amount of pressured water was conducted to the wash water tank to mobilize and recover the remaining solid particles. A total of 200 litres of wash water passed through the filter unit. The filters with solid particles were detached and stored. Of these, the 100 μm filter with solid particles were stored in a bottle with the filtrate water.

After the ice melted, the trailer contained 500 L of water. The filter unit was equipped with new clean filters. The water was pumped into the drain with the submersible pump (Mini

Monsoon XL 60) through the same flow meter and the filter unit as before. This way the microplastics carried by the ice were recovered. Again, the filters with solid particles were detached and stored. Of these, the 100 µm filter with solid particles were stored in a bottle with 0.5 L of the filtrate water. Figure 1 shows a schematic diagram of the preparation of the ice sample.

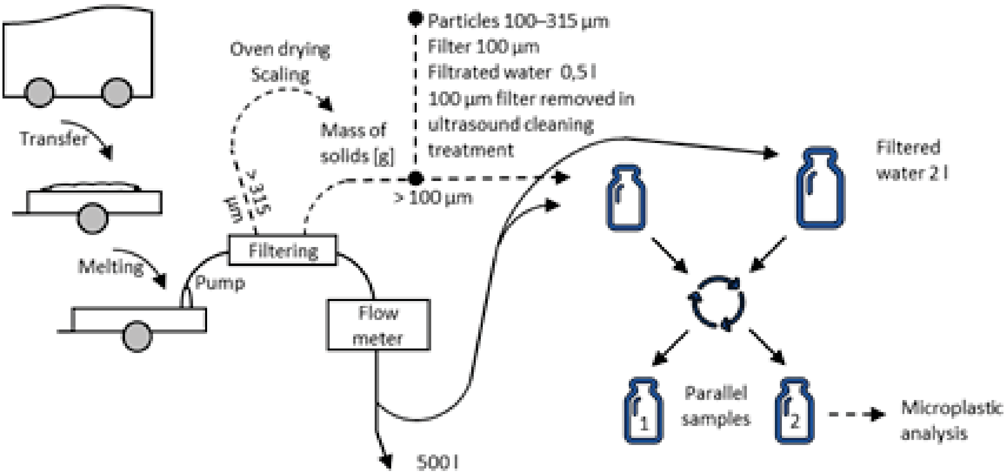

Fig. 1. Diagram of microplastic sample preparation

3. Results

Based on visual inspection, the solids found in the melted ice were black and yellow microplastics and black fabric fibers as seen in Fig. 2a. The yellow microplastics were known to be from the board structure of the hockey rink. The black particles and fabric fibers detached from the players' equipment and the puck during the game. Quantitatively, the yellow microplastics were few and they were very distinct from the dark particles. No residuals of the blue films were found.

The filters and solids attached to the filters were oven dried (70 °C, 4, 5 h). The melted ice contained 6.17 g of solids attached to the 315 µm filter. The mass of solids in the 100 µm filter was very small compared to the mass of solids collected in the 315 µm filter. Similarly, in Fig. 2b, the ice wash water contained 0.15 g of solids attached to the 315 µm filter. Also here, the mass of solids in the 100 µm filter was negligible compared to the mass of solids collected in the 315 µm filter.

Two parallel samples were prepared from the filtered water of the melted ice and the solids caught up in the associated filter of 100 µm. One of these samples was sent for analysis to Eurofins Ltd. With other words, this analyzed sample contained half of the collected solids having the size range of 100–315 µm. The particle distribution of this subset was assumed to be representative of the distribution of all collected microplastics. The liquid volume of the sample was 940 ml. The following types of microplastics were found in the sample: ABS, PA-6 PA-66, PC, PE, PET, PMMA, PP, PS, and PVS. During the analysis phase, the size of the examined microplastics was limited to a range of 27–1000 µm. In addition, the following micro-rubber types were found: PBR, PIR, and SBR. The size of the micro-rubbers examined was larger than 27 µm.

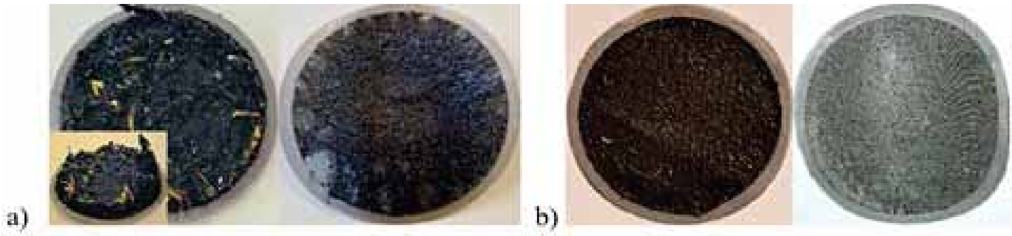

Fig. 2. a) Particles from melted ice water trapped in the 315 µm (left) and 100 µm (right) filter, the side view of the 315 µm filter shows the layer thickness of the particles; b) Particles from the wash water trapped in the 315 µm (left) and 100 µm (right) filter

Table 1 shows the types of the detected microplastics, the quantities, the detection threshold, and the measurement uncertainty, as well as the detailed determination of the material codes. Each type of microplastic had its own detection threshold. The measured quantities of the microplastics were typically hundreds of times greater than the detection threshold, except for PVC, which was below the detection threshold. The total quantity of microplastics sorted was 8065.7 µg/L, of which 3/5 were microplastics (4824.7 µg/L) and 2/5 were micro-rubbers (3241 µg/L).

Table 1. Microplastics and their subcategory micro-rubbers measured from melted ice. *LOQ* = Limit of quantification, *MU* = Measurement uncertainty

Row	*Plastics*		*Quantity [µg/L]*	*LOQ [µg/L]*	*MU [%]*
Microplastics (27–1000 µm)					
1	Acrylonitrile butadiene styrene	ABS	58.4	0.2	13.1
2	Polyamide-6 (Nylon-6)	PA-6	408	0.1	8.7
3	Polyamide-6,6 (Nylon-66)	PA-66	245	1	13.3
4	Polycarbonate	PC	134	1	48.3
5	Polyethylene	PE	2340	0.2	9.6
6	Polyethylene terephtalate	PET	667	0.2	35.7
7	Polymethyl metacrylate	PMMA	427	0.2	6.4
8	Polypropylene	PP	462	0.4	2.9
9	Polystyrene	PS	83.3	0.1	16.2
10	Polyvinyl chloride	PVC	< 3	3	5.7
Micro-rubbers (> 27 µm)					
11	Polybutadiene rubber	PBR	524	1	4.9
12	Polyisoprene rubber	PIR	2580	1	5.1
13	Styrene-butadiene rubber	SBR	137	0.2	5.3

Figure 3 shows the measured amounts of the detected microplastics in µg/L in order of concentration. The largest particle mass contribution was produced by PIR with 2580 µg/L, which represents 32% of all microplastics analyzed. The next highest was PE with 2340 µg/L. These two together represented 61% of all microplastics. The next microplastics contributing were PET (8%), PBR (6%), PP (6%), PMMA (5%), PA-6 (5%), PA-66 (3%), SBR (2%), PC (2%), PS (1%), ABS (1%), and PVC (0%).

4. Discussion

This study has investigated the microplastics and their subcategory micro-rubbers that end up on the ice during an ice hockey game. The microplastics types detected, from highest to lowest, were PIR, PE, PET, PBR, PP, PMMA, PA-6, PA-66, SBR, PC, PS and ABS. The amount of PVC micro-plastics was below the detection limit. In relative terms, PIR and PE contributed 61% of the mass of all microplastics. The high number of identified microplastics was quite surprising. One hockey game was estimated to produce about 20 g of microplastics [= 3x (6.17 + 0.15) g].

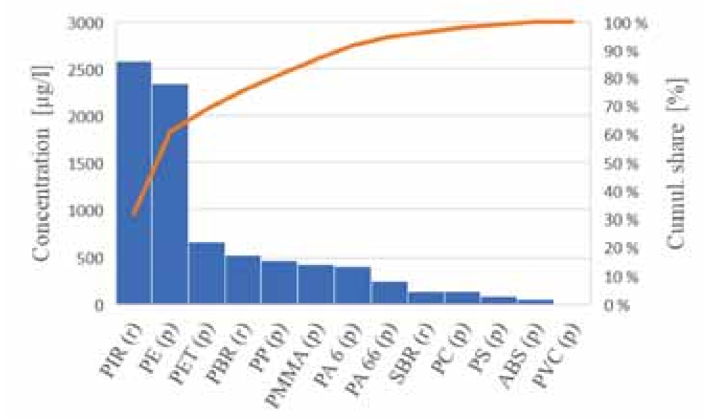

Fig. 3. Microplastics and their subcategory micro-rubbers types, quantities, and cumulative fraction measured in the melted ice, (*p*) = plastic, (*r*) = rubber

In the Finnish national professional league, 450 ice hockey matches are played every year in 60 rounds, and it can be estimated that about 10 kg of microplastics are produced. There are 223 ice rinks in Finland that support Finnish ice hockey from the highest league level to children's recreational hockey, so the total amount of microplastics generated annually can be conservatively estimated as "a few buckets full of microplastics". The ice piled up around the ice rinks will melt during the spring. Sometimes the accumulated ice is also recycled to make the base of cross-country ski trails. In both cases, microplastics are released into the environment and can end up in soil, run-off water, and water bodies. Ice wash water is discharged into the drainage system, from where it enters the water treatment process of water utilities.

Some of the microplastics can be assumed to be degraded to small airborne particles. As a game, hockey is a heavy and fast-paced sport, where the aerobic oxygen demand of the hockey players is high throughout the game. Consequently, the players' breathing rate and heart rate are also high. It is therefore possible that airborne microplastics can enter the players' lungs through the intense ventilation. On the other hand, during a heavy game, players drink a lot, which may cause micro-plastics to enter the stomach and from there onwards. The research design can be further developed by measuring airborne microplastics. This type of measurement could be carried out with a small collector system carried by a player. When integrating particle collection systems as part of a hockey player's equipment, player's safety must be considered. Another possible approach would be to place particle collection system above blue lines (bench), corners, and goals, where the players' close contacts take place.

5. Conclusions

Hockey serves as a significant example of a sport where microplastics are generated through close physical contact between players. The primary types of microplastics identified include polyisoprene rubber (PIR), polyethylene (PE), polyethylene terephthalate (PET), polybutadiene rubber (PBR), polypropylene (PP), polymethyl methacrylate (PMMA), and polyamide-6 (PA-6). Among these, PIR and PE particles constituted 61% of the microplastics by weight. On average, each game produced approximately 20 grams of microplastics, which varied widely in size.

A portion of these microplastics were released into the environment. In this case study, the majority of microplastics were deposited at ice and snow discharge sites. Additionally, some microplastics entered the city's water drainage system, contributing to broader environmental contamination.

Acknowledgements
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26th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 7th-10th November, 2023, Rimini, Italy

CIRCULAR CITIES: SCHOOLS AS A DRIVER FOR THE GREEN TRANSITION PROCESS*

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Abstract

Raising citizen awareness and fostering new forms of consumer behavior are among the priority actions of the transitional process towards circular economy. According to the social transition models, schools act as catalysts for the urban environment and therefore are able to maximize the impact of the ecological transition. Starting from these assumptions, a School Living Lab was developed by ENEA over the course of three school years, borrowing and adapting the Living Lab methodology. The project took place at the "Pitagora" Institute of Higher Education in the city of Policoro in the province of Matera (Basilicata, Italy). The activity was part of the broader ES-PA Project, Activity 3.2.3 "Integrated Territorial Projects for sustainable economic development", focused on the improvement of multilevel governance practices, the involvement of local stakeholders for the promotion and development of the circular economy approach.
The School Living Lab was organized in three steps: during the first year experts from ENEA trained and rose the awareness of the school community on sustainability and circular economy; during the second year the students ran an analysis of their needs and consumption habits and co-designed a circular economy project; finally, the third year was dedicated to the implementation of the project and to the following data analysis. The Living Lab included a nudge practice aimed at encouraging correct behavior in waste sorting and collection of recyclable plastic (bottle caps). The Living Lab also triggered a virtuous

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process of change by involving other local stakeholders, who collaborated independently to implement the practices. The project was concluded with the delivery of collected material to an Apulian recycling company, which transforms plastics into a secondary raw material for the production of streetlamps, thus closing the cycle of the polyethylene supply chain and proving the replicability of the School Living Lab experience.

Keywords: circular economy, living lab, nudge, raising awareness

1. Introduction

The transition from a linear to a circular economic system necessitates a significant shift in consumer lifestyles, thus requiring a cultural transformation in consumption practices. Promoting awareness and fostering new consumer behaviors are among the key priorities of policies aimed at transitioning towards a more sustainable economy. This cultural shift can only be achieved through coordinated collaboration among various societal actors. As emphasized by the European Commission's New Circular Economy Action Plan (EU-COM, 2020), the journey towards a circular economy must adopt a "co-creation" approach, facilitated by the cooperation of public institutions, economic players, citizens, and civil organizations. The active involvement of communities and individuals, especially in their roles as consumers and users, is a crucial component of the community action plan designed to accelerate the transition to a new circular model.

In the context of social transition, schools serve as potent catalysts within urban environments (Altenmueller-Lewis, 2012) and play a pivotal role in amplifying the impact of change and ecological transition (EU COM, 2022). Aligning with this perspective and relevant policy actions, the project described herein focuses on utilizing schools as drivers of intervention in civil society, specifically through activities aimed at educating consumers on sustainable consumption.

2. Materials and methods

Among the different methodologies for enhancing public participation and empowering citizens, we have applied the Living Lab (LL) methodology (https://www.ltu.se/cms_fs/1.101555!/file/LivingLabsMethodologyBook_web.pdf) in order to boost a bottom up process for the selection and implementation of actions towards sustainable and circular transition at the urban level. In doing that, the research project had two main methodological objectives: the former was to adapt the LL principles and approaches to a school context, thus giving life to a School Living Lab (SLL), i.e. a school laboratory with the involvement of pupils and teachers, in a participatory learning and co-creation process inclusive and shared.

The latter objective was to apply the principles of the Tinkering methodology to the LL (https://epale.ec.europa.eu/it/node/40449) or designing and implementing an idea with students in order to make the activity more inclusive and motivating.

The paper aims to highlight how LL theories, translated into a real case, can lead to very positive results and trigger virtuous processes of change.

3. Experimental

ENEA has involved citizens in various activities (Cappellaro et al., 2019; Morabito et al., 2021) and students in circular economy workshops whose purpose was not only to train and inform about the concepts of sustainability, conscious consumption and circular economy strategies but also to co-create community level projects on circular economy in order to improve the overall sustainability at the local level. According to the European Network of Living Labs (ENoLL) (https://enoll.org), the Living Lab (LL) is an open ecosystem based on a systemic approach of co-creation of innovative pathways within a community with the aim to evaluate ideas, experiment and share innovative solutions to be applied in real life contexts. In the framework of models of social transition, schools are a strong catalyst for the urban environment and a central element for amplifying the impact of change and ecological transition.

For the involvement of the reference community, i.e. the participants in the workshop path, both the ULLs (Urban Living Labs) and the SLLs use the same facilitation techniques (such as brainstorming, world cafés and open space technology). The fundamental difference between a ULL and a SLL on the circular economy consists in the type of final output of the process. ULLs, in fact, focus on the co-creation of design ideas that the community itself will then be able to implement to increase its circularity.

In the case of SLLs instead, the research project was also inspired by the principles of Tinkering which leads students not only to co-design an idea but also to implement it. This approach allows students to creatively experiment and explore their knowledge to find an original solution to a problem. In the context of SLLs, the Tinkering methodology is examined precisely for this aspect of "doing". The activities, in fact, are set up with the classic LL techniques: brainstorming, group work, exchange of ideas. Everything is aimed at designing an "object" which is the output of the “laboratory path”. Once the output was established, we applied the Tinkering approach for its realization, then we returned to the division of tasks and group work to implement what has been planned. This last phase was based on the class's ability to self-organize, with the supervision of ENEA researchers and teachers who plaied the role of facilitators. This allowed students to develop soft skills such as problem solving, communication, collaboration and teamwork.

The SLLs paths on circular economy implemented by ENEA are developed through 5 phases:

1. Engagement stage. The educational institutes interested in participating in the project activities are selected and the activities for the formalization of the collaboration between the research world and the school are carried out.

2. Establishment of educational laboratories. Each laboratory is made up of a certain number of pupils (eg. one or two classes, between 20/40 pupils each) and coordinated by one or more teachers. Researchers also participate in the laboratory with the role of disseminators/facilitators.

3. Planning phase of dissemination paths. Teachers and researchers plan the dissemination paths, co-designing interactive training activities, suitable for the audience of students participating in the laboratory.

4. Disclosure stage. Dissemination of the concepts of sustainability, circular economy, sharing economy, consumer education, closure of cycles, water saving, etc. is carried out by researchers according to the programs and methods co-designed together with the team of teachers, also with the help of games and videos.

5. Executive phase. The laboratory, using the methodology of open space technology and tinkering, elaborates a "final result" which can consist, for example, in the creation of dedicated teaching aids on the topics of the circular economy and environmental sustainability such as videos, articles, stories, comics or through the creation of an activity to be implemented in the school. The processed output is then created and shared not only with other pupils in the school and their families, but also outside the school environment.

4. Results and discussion

The SLL described in this paper began during the 2020/2021 school year, with the provision of 5 info-training modules for students of selected classes in order to build a school community (CS) of reference trained and aware of the issues of the circular economy. The topics covered by the researchers, in agreement with the school tutor, dealt with environmental issues, the circular economy in its various forms including notions of the methodologies of closing the cycles, the strategies of the circular economy in cities and territories, the sharing economy, the concept of sustainable consumption. Once all this information was acquired, the CS selected two topics among those covered and imagined how it would be possible to represent them through a short movie picture. The CS elaborated the two screenplays through comic representation (story board) and, with the funding of the project, two films were made: Myth of the cave (https://www.youtube.com/watch?v=KZzx3Es5-kM) and Smartphone story (https://www.youtube.com/watch?v=_M-wPppguNU), interpreted by the students themselves.

During the 2021-22 school year, the CS developed and disseminated a questionnaire to learn about the circularity needs of the students of their school. 160 fully answered questionnaires were collected. Following the results of the survey, CS evaluated the options on the possible output and set itself the goal of devising, planning and implementing a circular economy practice related to encouraging correct behavior in separation of plastic materials at the end of life of products. Therefore, a nudge experiment was co-designed in the form of a game. The game consisted in "electing" the most popular well-known characters (or goods/services) within the students community. The vote could be expressed by inserting previously collected plastic caps into the "ballot box" of the preferred subject. In order to stimulate the participation multiple vote was allowed and the ballot boxes were transparent so that a constant comparison between the two "champions" was allowed.

Nudges are strategies that are useful for inducing people to perform certain actions, without there being any obligation to do so, but only as an incentive. In this case, the challenges have been useful to encourage the separate collection of PE (Polyethylene) caps. This activity was presented through a public event at the beginning of the third year of SLL, during the 2022/23 school year, on the occasion of a cultural event in the city, which took place on October 1st 2022. In the following 6 months, after 4 challenges, 31.5 kilos of plastic caps were collected, equal to about 16.000 caps.

The initiative has also triggered a process of voluntary participation in the collection activity by both other schools and local businesses, demonstrating how the school can be an effective driver of change within an urban community, and trigger an effective circular transition process.

The SLL process also served to demonstrate how the secondary raw materials collected can be reused in new productions. In fact, the caps collected were delivered to the Niteko company which uses recycled PE as a secondary raw material for the production of streetlamps. The company actively participated in the last stages of the process, welcoming students to its factory to show them the production lines and explaining the technologies used in the production of streetlamps (March 29th, 2023) and later participating in a final event (May 11th, 2023) presentation of the results of the laboratory course at the Pythagoras institute. The Event involved all the actors of the project and local authorities for future follow up and replication of the project.

5. Conclusions

The SLL (Sustainable Living Lab) initiative on the circular economy, implemented by ENEA at the Pythagoras Institute of Policoro, served as a pioneering "pathway" aimed at fostering a cultural shift in consumption patterns. This initiative specifically targeted younger generations, enhancing their awareness of the critical need for transitioning to a circular economy and equipping them with the necessary tools to support a more sustainable economic system.

The SLL initiative has demonstrated considerable effectiveness in achieving these objectives. It has significantly impacted the education of students, facilitating the cultural transformation in consumption behaviors that aligns with the goals outlined in the New Circular Economy Action Plan. Through hands-on experiences and practical learning, students have not only grasped the importance of sustainable consumption but have also become advocates for circular economy principles, thereby contributing to a broader societal shift towards sustainability.

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URBAN CIRCULARITY THROUGH A MULTISTAKEHOLDER APPROACH IN THE FRAMEWORK OF CULTURE AND CREATIVITY*

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Abstract

A strategy for the implementation of circular economy at urban level is a more effective dialogue between the cultural, social, economic and environmental sectors, with the co-creation of operational synergies, through the involvement of the territorial community. In the framework of Basilicata Heritage Smart Lab, a research project aiming to enhance the tangible and intangible cultural heritage of Basilicata, a Southern Italy region, ENEA contributes to the activities of Work Package 4 "Basilicata Living Lab", with the aim of building a more sustainable territory and society, through the circular economy approach within the cultural and creative setting. Specifically, this project proposes the engagement of consumers/citizens as active participants to achieve the circular transition. Such engagement is made possible by culture and creative industries, having both economic and societal roles.
The pilot activities have been carried out through the implementation of a heritage smart lab, a multidisciplinary group of researchers, entrepreneurs, local government, active citizens and social innovators, in the city of Venosa, an ancient town in Basilicata. By leveraging coalitions of local actors,

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the pilot activity focused on the socio-cultural regeneration as the starting point to steer collective inquiry into their meanings and narratives and co-create new visions and utilization of public spaces. Awareness-raising efforts ended in a deeper understanding of the need to take actions rooted in the co-creation of new sustainable activities based on sharing economy, lengthening product life cycles through reuse, repair, re-manufacturing and re-furbishment. In this context, the participants, led by ENEA researchers, outlined the proposal of requesting, to the municipality of Venosa, a space to implement and spread circular economy activities for the local community. Throughout the smart lab approach, culture and creativity supported the engagement, helping to enrich social and cultural integration, consolidating, adjusting and providing new directions of urban development.

Keywords: circular economy, creativity, culture, urban living lab

1. Introduction

Urban areas are the main field of experimentation to face environmental challenges. According with the Sustainable Development Goal 11 of United Nations, in the next years cities should become creative ground of collaboration between different stakeholders to improve the urban environment and preserve the environment and the health of citizens. Consequently, a massive experimentation of collaborative processes was promoted around the world (Mukhtar-Landgren et al., 2019).

Likewise, urban experimentations, such as Living Labs (LLs), in the field of circular economy, are considered of fundamental importance to build innovative long-term policies by finding out new products, platforms and solutions (Savini and Bertolini, 2019). At the European level, the shared objectives for the green growth at urban level are related to a more effective dialogue between the cultural, social, economic and environmental sectors, in which culture and creativity have a strategic role for social and place-based innovation with the co-creation of operational synergies, through the involvement of the territorial community https://www.coe.int/en/web/conventions/full-list?module=treaty%20detail&treatynum=199) empowering communities thanks to collaborative decision-making processes (Cerreta et al., 2020).

The research activities described in this paper have been developed in the framework of the Basilicata Heritage Smart Lab, a research project promoted by the Cluster of Cultural and Creative Industries of Basilicata, “Basilicata Creativa”, based on the involvement of about twenty pilot cultural sites, which reflect the wide complexity of the Lucanian cultural heritage. In every pilot site a Heritage Smart Lab (HSL) has been set up. A HSL is a multidisciplinary group of researchers, entrepreneurs, young talents, active citizens, experts and innovators, involved to co-create different interventions applied to the conservation, enhancement and use of the tangible and intangible cultural heritage of that site. The project is structured in four Work Packages (WPs), each of them having a different objective and a specific output.

The paper illustrates part of the WP4 activities, the HSL named “Basilicata Living Lab” implemented by the ENEA research team in the city of Venosa, an ancient town in Basilicata, with the cooperation of the city government, many local associations, citizens and the Cluster “Basilicata Creativa”.

The main objective of the HSL work realised in Venosa has been the activation of an urban community in order to co-design circular economy activities related to the cultural and creative supply chain, on the basis of the specific territorial needs and peculiarities, involving different actors, both public and private, so as to be able to analyse the urban context and its issues from multiple perspectives.

The Living Lab (LL) methodology has been used for both community engagement and co-design process, that was developed and modelled on the specific needs and peculiarities of the project. The work aims to highlight how the participation of a community in a creative process of co-creation of new development forms of an urban area, can lead to achieve important results, as highlighted in sections 3 and 4.

2. Materials and methods

The LL methodology employed and fine-tuned for this specific activity was implemented following an in-depth literature study and referring to other activities carried out by the research team (Cappellaro et al., 2019; Morabito et al., 2021), as well as to the activities carried out in the RECiProCo project (https://www.reciproco.enea.it/). In Europe, LLs are seen as instruments to achieve greater citizen participation and social cohesion (Edwards-Schachter et al., 2012).

Such approach has also caught the attention of the European Commission, that since 2009 is promoting a common European innovation system, based on LLs (European Commission, 2009), with the aim of sustaining the objective of Lisbon Strategy (European Parliament, 2009) and reinforcing the economic competitiveness of the continent.

These actions led to the creation of an organisation named ENoLL (European Network of Living Labs, https://enoll.org/) which defined a Living Lab as a space of open innovation, dealing with real life situations, aiming to the active involvement of final users (citizens), thus realizing co-creation pathways of new services, products, and social infrastructures.

Particularly, LLs are considered effective instruments in the activation of circular urban transition (Cuomo et al., 2020).

The LL methodology, developed starting from a previous experience of the authors in the Reciproco project (https://www.reciproco.enea.it/), has been structured, according to the peculiarity of the present work, into four main phases, that are hereafter described.

1. Scouting phase: territory study and stakeholder identification.

2. Listening/exploration phase: stakeholder invitation at a public event, project presentation, development of a survey through a questionnaire for identifying the main needs and interest of participants and territory. Starting from the results of these activities, the LL meetings are organised, in four consecutive meeting, each one having the duration of three hours.

3. Participation phase: 1st and 2nd meeting, focused on capacity-building (info-formation and awareness), experience exchange between participants (cross-fertilization), identification of main topics, first co-ideation of LL outputs.

4. Execution phase: 3rd and 4rd meeting, destined to the co-planning of circular economy activities to be achieved in the area of interest.

The final result consists in a document describing the project proposal about circular economy designed and chosen for implementation by the participants.

3. Experimental

With reference to the methodology described in the previous section, the experimental work has been organised as follows:

1. Scouting phase: the first step of the LL implementation process in the present research project has been achieved through various meetings between the ENEA researchers and the administrators of Venosa city, in order to identify and co-define the activity objectives, the most suitable stakeholders, the place hosting the living lab meetings, the meeting schedule. Regarding this aspect, the administrators have allowed the use of public spaces for the implementation of living labs, which were scheduled in five meetings, from 1st March and 10th May 2023. The scouting phase also included the territory study carried out from literature works.

2. Listening/exploration phase: the beginning of this phase has been represented by a public event, held on March, 1st, 2023, with the invitation of citizens, association members,

company representatives. During the meeting, the aim and the organisation of the LL has been presented to all the participants, who received a survey, in the form of a questionnaire, aiming at identifying the topics of main interest, the needs of the participants, and their knowledge about circular economy, in order to define the LL framework and, above all, the circular economy activities considered as primary for the territory of Venosa. The survey, having 21 subscriptions, underlined the need among citizens of having the possibility to use public spaces to be destined to circular economy activities within the cultural and creative fields, in order to give rise to new forms of sociality and territorial development.

3. Participation phase: this phase has been implemented in the initial LL meetings (1st and 2nd). In the 1st meeting (March, 22nd, 2023) the attending citizens were informed about the specific objectives of the Laboratory, consisting in the activation of participation processes of socio-cultural regeneration for the territory of Venosa, through co-ideation and co-planning of project proposals based on circular economy principles. Moreover, with reference to the findings of the municipalities adhering to the Circular cities declaration (https://circularcitiesdeclaration.eu/), some examples of urban circularity have been illustrated to the participants. In the 2nd meeting (April, the 12th, 2023), the ENEA researchers examined the circular economy aspects of agri-food and water sectors, thus giving rise to a brainstorming between citizens on the suitable activities to be implemented on the territory.

4. Execution phase: in the 3rd meeting (April, 16th, 2023) different bio-refurbishment techniques, based on natural methods, used to protect the cultural heritage, have been illustrated to the citizens. Then, the co-planning phase has taken place, adopting the world-cafè methodology (https://theworldcafe.com/key-concepts-resources/world-cafe-method/): the 15 participants have been divided into 2 working groups, both discussing about the question:" In the case of having at your disposal a public building/space to be destined to circular economy activities aiming at awareness rising and knowledge increasing in the community of Venosa, what would you/your association suggest?". Starting from this issue, the participants outlined their ideas, writing them on a collective poster. Finally, the different ideas have been summarized and displayed in a template form for the proposal co-planning.

In the 4th meeting (May, 10th, 2023), the two groups shared their ideas, again adopting the world-cafè methodology: each new worktable was constituted by a representative of a certain group and the members of the other group. The leader illustrated the ideas of his group to the new participants, who, from their own perspective, shared new opinions, suggestions, and integrations.

The raised project proposal has been called "Fucina in circolo-Idee e attività sull'economia circolare"- "Circular forge-Ideas and activities about circular economy".

Such proposal has been originated from the condition of having a public space for the co-creation of new forms of culture, awareness and sociality, through the shared implementation of various kinds of circular economy activities, all linked to processes of education, sensibilization and cultural growth, such as creative re-use courses, anti-waste cooking courses, second-hand good sharing through a virtual or physical platform (for example book sharing), exhibitions about old knowledge and traditions, energetic communities.

The Circular forge could be achieved only with the support of the administrators of the city of Venosa, who should identify a public space to be shared with the proponent group, as well as through collaborations with research centres and land companies.

4. Results and discussion

The proposal co-designed in the LL, starts from the assumption of having a public space by the municipal administration, to be dedicated to the co-creation of new forms of culture, awareness and sociability, through the realization of different circular economy activities, related to educational processes, awareness and cultural growth, as well as inclusiveness and new forms of sociability and sharing.

The continuation of the activity envisages the identification of the public space to be allocated to the activities and the definition of a collaboration agreement for the public-private co-governance of this space, and at the same time the search for forms of financing, both public and crowdfunding forms, to be able to implement the activities.

5. Conclusions

Venosa HSL, utilizing the Living Lab (LL) methodology, presents a significant and innovative development proposal for a small city. This initiative aims to initiate pathways and processes for urban and socio-cultural regeneration from the ground up. By fostering collaborative approaches, it stimulates the creation of new social networks and forms of cooperation between citizens and local government.

These pathways enhance cultural capital through the interaction and exchange of expert and community knowledge. They strengthen community ties, create opportunities for inclusion, and contribute to the reimagining of local services. Ultimately, Venosa HSL formulates a new vision for the territory, founded on cooperation and co-responsibility. This approach not only revitalizes the urban environment but also promotes a sustainable and inclusive community development model.

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SURVEY BASED ON CIRCULAR ECONOMY APPLIED ON THE TRANSPORTATION SECTOR*

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Abstract

Assessing the level of circularity in a specific geographical area is a far-from-easy task; the method followed was the administration of a survey and processing of the data obtained. The empirical study focuses on the transportation sector, as it has great potential to become a driver of circular economy in Sicily. The aim of this paper is to suggest new methods and initiatives for organizations to improve their environmental consciousness, thus actively participating in the green revolution. In order to obtain a valuable benchmark, a specific survey aims to take a snapshot of the current situation in businesses to promote relational networks, best practices and sustainable styles for the corporate world, involving universities and institutions. A sustainable business model is achieved above all through a corporate culture that is capable of transmitting the values of recycling, reuse and efficient use of resources to all those involved in the production process and that manages to involve as many people as possible.

Keywords: circular economy management, environmental impact, survey, transportation sector

1. Introduction

The concept of circular economy was first introduced in 1966 by Kenneth Ewart Boulding in his book, “The Economics of the Coming Spaceship Earth”, in which he argued that for millenniums human beings have idealized their existence as though developed on a limitless plane, rather than on what Earth actually is: a sphere; this belief led them to the idea that there would always be somewhere else to go, something else to explore and discover,

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beyond the limits of human habitation. That was, of course, until it was discovered that Earth is, in fact, a sphere, forcing mankind to perceive their own planet, and most importantly their life on it, in a profoundly different way: no longer an open cycle, but rather a closed one, a paradigm shift that economists still strive to accept. According to Boulding (1966), the employment of a circular economic system is the only way to ensure human life on Earth while simultaneously meeting consumers' ever-growing demand.

It wasn't until 1989 that Pearce and Turner coined the phrase "circular economy" and proceeded to integrate Boulding's ideas by referring to the second law of thermodynamics, which states that the entropy of an isolated system increases over time, and thus devalues higher order energy or material. Entropy is the measure of the disorder of a system: the more uniform energy and material are, the lower the entropy. However, linear economy is based on the extraction of more and more resources in order to utilize them as inputs in production processes, thus increasing the level of entropy (Geisendorf and Pietrulla, 2018). Circular economic models would substantially reduce the need for virgin raw materials and ultimately delay the increase of entropy (Andersen, 2007).

Since Boulding's book was published, over 114 definitions have been generated by scholars and practitioners, though the most recognized one was provided by the Ellen MacArthur Foundation, according to which "[Circular Economy] is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" (Kirchherr et al., 2017).

The transport industry, though determinant to the global economy, has been proven to be one of the leading causes of pollution and climate change: traditional means of transportation release severely harmful gases and carbonaceous particles into the atmosphere, with disastrous consequences in terms of health and environment. Automobiles and all gasoline-powered vehicles rely on combustion, a chemical reaction that emits water vapor (H_2O) and carbon dioxide (CO_2) (Colvile et al., 2001): it is estimated that 22% of all CO_2 emissions derive from motor vehicles; moreover, according to the EPA (https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation), GHG emissions from transportation account for about 29% of total GHG emissions in the United States as of May 2023. Globally, in 2022 CO_2 emissions from the transport sector grew by more than 250 Mt CO_2 to nearly 8 Gt CO_2, according to the IEA (International Energy Agency, https://www.iea.org).

Other pollutants are nitrogen oxide (NO) and its oxidized products nitrogen dioxide (NO_2); the quantity of NO_x produced depends on three factors: the amount of time taken or the combustion duration, the level of concentration of oxygen and the maximum existing temperature in the combustion cylinder (Semakula and Inambao, 2018).

Ship emissions can have considerable impacts on atmospheric concentrations in coastal areas of CO_2, NO_x, SO_2, CO, hydrocarbons, PM_{10} and $PM_{2,5}$ (Matthias et al., 2010); the two most important types of pollutants connected with railway transport are polycyclic aromatic hydrocarbons (PAHs) and heavy metals (Wiłkomirski et al., 2011); airport emissions (AEs) have received increasing attention in recent years due to the rapid growth of air transport volumes: although exhaust plumes from aircraft engines were conventionally considered to account for most of the emissions, other sources are present within modern airports and contribute to air pollution at the local scale. Among these, tire, brake and asphalt wear and the resuspension of particles due to the turbulence created by the aircraft movements can account for large fractions of total particulate matter mass (Masiol and Harrison, 2014; Oliveri et al., 2023).

The present work focuses, through the administration of a survey to 10 Sicilian companies, on assessing their current and/or future environmental efforts. The results obtained portray a clear depiction of the current circumstances, relatively more optimistic than most would assume, and represent a significant starting point for future implementations and initiatives.

2. Materials and methods

According to the definition provided by the OECD (Organization for Economic Cooperation and Development), an indicator is "a quantitative or qualitative factor or variable that provides a simple and reliable mean to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor" (Saidani et al., 2018). Indicators are greatly powerful tools as they can be employed to set goals, raise awareness, support education, track progress: essentially, they are able to quantify and simplify complex phenomena.

Even the European Commission (2015) has recognized the importance of indicators through its action plan: "To assess progress towards a more circular economy and the effectiveness of action at EU and national level, it is important to have a set of reliable indicators".

The indicators of circular economy, the so-called C-Indicators, operate on three levels: micro (companies, consumers), meso (eco-industrial parks) and macro (cities, regions, nations) (Corrente et al., 2023). Kristensen and Mosgaard (2019) reviewed 30 micro-level indicators, the majority of which focus on recycling, end-of-life management or remanufacturing, while fewer consider disassembly, lifetime extension, waste management, resource-efficiency or reuse. The 30 indicators were then divided into three categories, based on the nature of their output: quantitative singular indicators, which present circularity as a single number, analytical tools, which provide guidelines and models, and composite indicator sets, which combine the previous two categories. Some of these indicators include the MCI (Material Circulation Indicator), which quantifies the impact of a certain good in terms of raw materials consumption (Kristensen and Mosgaard, 2019), the Circular Economy Index (CEI) which calculates the ratio between the material value achieved from recycling end-of-life products and the material value needed for (re)producing end-of-life products (Di Maio and Rem, 2015), the LI (Longevity Indicator) which measures the length of time for which a material is retained in a product system (Franklin-Johnson et al., 2016), the EOLI (End-Of-Life Index), a composite indicator that consists of other End-Of- Life indices; it employs a cost-based approach as it calculates the costs associated with the disposal and disassembly of a product once it reaches the EOL stage (Kristensen and Mosgaard, 2019).

The meso level is associated with eco-industrial parks; according to De Pascale et al. (2020), an eco-industrial park is "a group of firms settled within an area that tries to enhance economic, environmental, and social efficiency under reciprocal collaboration, with the aim to generate a greater common advantage than the summation of the single advantages that firms would obtain without cooperation". At the meso level, Chinese governmental agencies NDRC and MEP have developed two sets of Eco-Industrial Parks (EIP) Evaluation Indicator Systems.

The NDRC system involves four dimensions: resource output rate (the amount of production value generated from one unit of material, land, energy and water consumption), resource consumption rate (energy and water intensity to track resource efficiency), integrated resource utilization (the reuse rate of industrial water and the recycling rate of industrial waste) and reduction rate in waste discharge (reduction in industrial waste discharge).

The MEP system involves four dimensions as well: material reducing and recycling, economic development, pollution control and administration and management perspectives (Su et al., 2012).

Most circular economy studies on the macro-level have been conducted in China due to the country's spectacular economic growth that has occurred at the environment's expense, forcing the Chinese government to elaborate and regulate several (macroeconomic) C-Indicators; once again, the NDRC developed an evaluation system of macroeconomic circular indicators divided in 4 categories: resource output (it refers to the amount of GDP produced from resource consumption, the higher the values of these indicators, the higher the material efficiency), resource consumption (it refers to the amount of resource consumed on a per unit product or per unit GDP level), integrated resource utilization (it reflects the level of material recycling and dematerialization perspectives of an economic system) and waste disposal/pollutant emission indicators (it refers to the total amount of waste disposal and the emission amounts of key pollutant) (Geng et al., 2011).

If a paradigm shifts from linear to circular economy is far from easy on the micro and meso levels, it is even more challenging on the macro level; sets of indicators are of the utmost importance as they are able to monitor and evaluate the current state of an economic system, leading to great economic and environmental benefits.

The indicators observed mostly emerged from empirical studies conducted by environmental scientists, economists and academics. However, non-governmental organizations, such as the ISO (International Organization for Standardization) or more specifically the UNI (Italian National Unification), have also elaborated and regulated new indicators (Golinucci et al., 2019).

One of the most promising C-Indicators is LCA (Life Cycle Assessment), a methodology regulated by the ISO, which allows an evaluation of the environmental impacts of products, processes and services, from cradle to grave; more specifically, LCA is defined by the ISO as "the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (Camana et al., 2021).

LCA was first introduced in 1997 through the ISO 14040 series (ISO 14040, 1997), which described the 4 phases to analyze environmental aspects of a product in a systemic way. The first phase, goals and scope definition, is arguably the most complex as it aims at determining the product system boundary (cradle-to-gate, cradle-to-grave, gate-to-gate and so forth) as well as the functional unit. Once enough data is collected and available, it is possible to create an inventory of material and energy use associated with each life cycle stage. In the third phase, the environmental load of a certain product, quantified and categorized in an "inventory" (through a process called "characterization"), is later translated into potential impact on human health (Scrucca et al., 2023).

The interpretation represents the key phase of the whole system: once the life cycle of a product has been observed and analyzed, its energy and material use has been quantified and later categorized based on how impactful it is in terms of environmental and health damages, it is of crucial importance to interpret such results through a critical review and to elaborate and later implement new strategies and new methodologies to the production process (Lee and Inaba, 2004).

On November 30th, 2022 the UNI published the technical specification UNI/TS 11820: "Measurement of Circularity – Methods and Indicators for Measuring Circular Processes in Organizations" (UNI/TS 11820, 2022). The standard defines a set of indicators applied at meso and micro levels, suitable for assessing, through a rating system, the level of circularity of an organization or group of organizations; the rating system does not provide minimum levels of circularity but provides an assessment of the level achieved. It includes a set of 71 indicators divided into 7 categories: material resources and components, energy and water resources, waste and emissions, logistics, product and service, human resources, asset and policy, sustainability.

Specifically, as suggested by the specification, the level of circularity should be assessed within each group of indicators since it helps to evaluate the areas of intervention more precisely. The specification heavily relies on complementary approaches such as life cycle thinking, material flow analysis, resource value maintenance, value recovery and continuous improvement, and it becomes a pivotal step toward the future ISO 59020, set to provide a tool to measure circularity on an international scale (Amicarelli and Bux, 2023).

3. Results and discussion

As previously argued, transportation is a leading cause of pollution, at least in its traditional forms; the attainment of sustainable transport is a duty and a responsibility for all human beings in an effort to guarantee future generations the fulfillment of the need to move from place to place.

In order to achieve sustainable transportation, it is necessary to study and employ indicators specifically elaborated for the sector; such indicators serve four functions: information, assessment/forecasting, evaluation/monitoring, control. Information-oriented indicators aim at providing a deeper understanding of environmental issues; forecasting-and-assessment-oriented indicators are employed to compare expected trends or the results of a particular project with policy objectives; evaluation and monitoring are fundamental activities in transport planning and policy, mostly to compare developments in transport systems; finally, control-oriented indicators are used in managing transport contracts (Gudmundsson, 2004).

A 2011 study identified 3 main groups of indicators: Transportation Environmental Impact Indicator (TEII), mostly referring to urban transportation local emissions, energy use and land consumption; Transportation Economic Impact Indicator (TCII), which includes local government budget in the transportation sector as well as the aforementioned household expenditures on transport; Transportation Social Impact Indicator (TSII), related to transportation accessibility, variety of transportation options and transportation death. The three groups together represent the sustainable transportation indicators (Haghshenas and Vaziri, 2011).

A sustainable business model is achieved above all through a corporate culture that is capable of transmitting the values of recycling, reuse and efficient use of resources to all those involved in the production process and that manages to involve as many people as possible. Indeed, it is essential that all company functions take part and collaborate in the transition process, from the R&D department to the HR department, from marketing and communications to the purchasing and supply procurement department. It also turns out to be of the utmost importance for the company to include its employees, suppliers, customers and stakeholders so that the project takes place in a more structured and effective form.

In order to obtain a valuable benchmark, the survey, developed with the support of the professional services of PwC, aims to take a snapshot of the current situation in businesses to promote relational networks, best practices and sustainable styles for the corporate world, involving universities and institutions.

The survey was administered to 10 companies in the transportation sector, all located in Catania, Sicily; the choice of the sector comes from a strong belief that, although it currently is extremely polluting, transportation represents a great opportunity for circularity, and the data collected is proof of it.

The survey can be divided into 4 sections: the first section, from question 1 to question 6, is purely descriptive and it aims at providing background information on the company; although the names of the respondents will remain anonymous, it is interesting to frame the sizes of the companies based on the number of employees and average annual revenue (70% of the companies interviewed have an average annual revenue of over €2M).

The second section, from question 7 to question 9, highlights the company's current efforts in the circular economy field. More specifically, the respondents were asked about the voluntary certifications acquired and the presence of a professional figure in the company that deals with environmental sustainability and circular economy.

In most cases the respondents have acquired at least one certification, proving that environmental sustainability and high-quality products and processes already are a major concern for Sicilian entrepreneurs; in nearly all cases examined, there is not a professional figure responsible for environmental sustainability. In the singular case of an affirmative answer to the question, the figure is that of the Environmental Sustainability Manager.

The third section, from question 10 to question 12, aims at determining the company's future perspectives and medium/long-term projects inherent to environmental sustainability; 90% of the respondents have already undertaken such projects or plan to do so in the near future, while the most affected areas have been or will be energy consumption, reduction of emissions and reduction of traffic congestion. The fourth and last section, from question 13 to question 20, serves as the survey's core as it includes opinions, impacts, best practices, barriers and opportunities of circular economy. Although it is quite evident that circular economy has the potential to impact every single aspect of a company, according to the respondents, the most impacted one will be sustainable mobility (Fig. 1). Environmental impacts of traditional transportation means are mostly quantified as shown in Fig. 2.

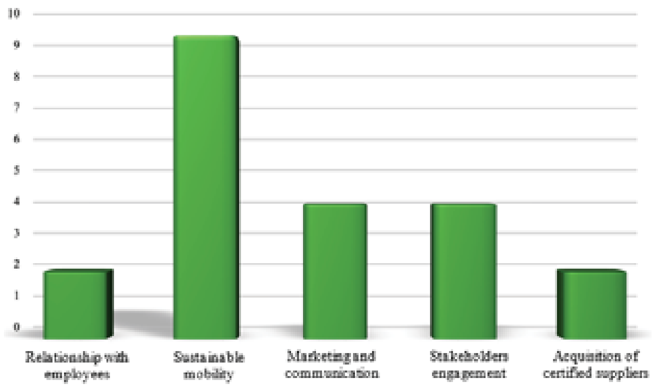

Fig. 1. Impacts of circular economy

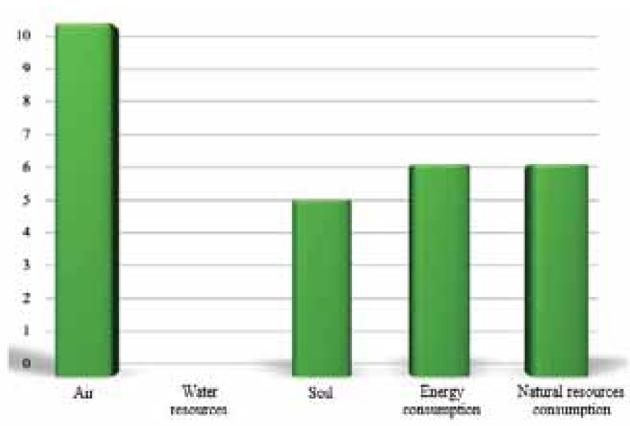

Fig. 2. Current environmental impacts

Some of the best practices (question 14) already implemented in the companies interviewed include the installation of a photovoltaic system, the employment of intermodal transportation that, through the combination of roads and waterways, is able to reduce emissions, optimization of transportation planning with a further reduction of fuel used (road optimization), closed-loop and reverse-osmosis bus-washing system for industrial water recovery, renewal of the vehicular fleet, installation of intelligent control units that allow all traffic lights to be synchronized to the color green in a given time frame (green wave). Moreover, all participants resort to waste sorting and outsource the waste management service to third-party companies (question 15).

Questions 18 and 19 focus on barriers and opportunities associated with circular economy; all the companies interviewed agree on financial resources being a significant obstacle to the green transition, further proving that, as already stated, everyone needs to take part in the process, including institutions that can provide the funds companies need. Other barriers are the length of processes to acquire certifications or implement new projects, as well as cultural biases, mostly due to the lack of awareness among people. The opportunities mentioned are numerous and include staff-training programs to educate employees on the importance of sustainability, improved local public transport, increased awareness, more efficient services due to intermodality, and, almost paradoxically, more abundant financial resources once circular business models are implemented.

The results presented prove that Sicily is not as far behind as one could think; indeed, there still is some work to do, starting from the lack of professional figures of environmental sustainability in companies, as they have deep knowledge on how to recycle residual materials, recover resources and dispose of waste; moreover, they can contribute to the implementation of circular business models and provide advice and suggestions to the management.

In more than half of the cases examined, there are no programs or training actions implemented to share circular economy's principles with employees; as important as the aforementioned professional figures are, environmental management cannot be limited to a small number of experts, but rather everyone within the company should be familiar with sustainability: companies are systems with their own sets of values which should be shared and absorbed by every single component. Managers cannot expect to succeed in circular strategies unless everyone in the team firmly believes in them.

Moreover, the Covid-19 pandemic proved that smart working can easily be implemented with great results in terms of productivity, and most importantly, in terms of environment. An ENEA study on the impact of smart working in four Italian cities (Rome, Turin, Bologna and Trento) found that remote working avoids the emission of around 600 kg of carbon dioxide per year per worker (-40%) with considerable savings in terms of time (around 150 hours), distance traveled (3,500 km) and fuel (260 liters of petrol).

4. Concluding remarks

The implementation of circular economy can also be nurtured by partnerships with universities; as sustainability is becoming more and more object of academic interest, scholars are acquiring significant skills in the field, and their involvement can substantially boost the green transition, not only through the implementation of projects developed by them, but also through the dissemination of CE's pillars, thus contributing to increased awareness.

Although such suggestions are valuable and represent powerful tools for companies to adequate to new environmental circumstances, it is of the utmost importance to study companies' level of circularity, and that is what the survey aimed at; the questions are not meant to diminish organizations' efforts in terms of environmental sustainability, but rather to stimulate them to wonder what else can be done, which projects can be developed, which new strategies can be pursued, which new best practices can be implemented.

The creation of new innovative solutions to reduce the impacts of virtually any activity carried out by humans is a slow but steady process, and it is through the combination of what is already being done and what can still be done, that a new paradigm for entrepreneurship can be established: that of circular economy.

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REMOTE MONITORING OF SOLID WASTE AND RELATED COST EFFECTS FOR A HOUSING COMPANY*

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Abstract

This case study presents results on a follow-up study for real-time monitoring of waste infra and related optimization of waste logistics. Study was carried out for a housing company in Espoo, Finland for nine months during 2022-2023. Housing Company Waste Infra consists of 7 deep waste collection containers for separated waste fractions (mixed waste, carton, paper, plastic packages, biowaste, metal, glass). First part of the study, 3 months, consisted on fill level monitoring. In the second part of the study, updated emptying routines for deep collection bin emptying were implemented, according to monitoring results. Third part of the study consisted on cost saving estimations for the Housing Company, with payback time/SaaS-service calculations. Based on the results, annual costs for the waste management for housing company decreased 21% concerning transportations with new practices.

Keywords: monitoring and assessment tools, smart waste management, waste management

1. Introduction

Implementing a smart waste management system requires an initial investment in technology and infrastructure, but the long-term benefits in terms of cost savings, environmental impact reduction, and resident satisfaction can be substantial. It's a forward-thinking approach that aligns with the goals of sustainability and efficiency in housing management (Finlex, 1999). Municipal waste collection and treatment are essential public services for every community and efficient logistics and recycling of wastes are needed for the protection of public health and the environment. The impacts of real time monitoring of wastes

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were studied in one housing company to find out what kind of impacts it could have to logistics and waste management costs (Kuusamon kaupunki, 2020).

As a big picture, implementing smart waste management system includes following features:

IoT sensors: the foundation of smart waste management is the installation of sensors in waste bins or containers. These sensors can detect the level of waste and transmit real-time data to a central management system. This information helps housing companies determine when bins are full and need to be emptied, reducing unnecessary collections.

Data analytics: the data collected from sensors can be analyzed to identify patterns and trends in waste generation. This information can be used to optimize waste collection schedules, allocate resources efficiently, and reduce operational costs.

Route optimization: smart waste management systems can calculate the most efficient collection routes for waste trucks, minimizing fuel consumption and reducing emissions. This reduces the environmental impact of waste collection and lowers operational costs.

Predictive maintenance: sensors can also monitor the condition of waste bins and equipment, detecting issues such as damage or malfunctions. Predictive maintenance can help housing companies address problems proactively, reducing downtime and repair costs.

Recycling and sorting: smart waste management can incorporate recycling stations with sensors and cameras to encourage rmesidents to separate recyclable materials from general waste. These stations can provide feedback and incentives to promote recycling.

Mobile apps and notifications: housing companies can develop mobile apps for residents to report waste-related issues, schedule special pickups, or receive notifications about collection schedules and recycling events. This improves communication and engagement with residents.

Cost reduction: by optimizing waste collection and reducing operational inefficiencies, housing companies can significantly lower waste management costs over time. This can lead to cost savings that can be reinvested into community improvements.

Environmental sustainability: smart waste management reduces the carbon footprint associated with waste collection and disposal. By optimizing routes and promoting recycling, housing companies contribute to environmental sustainability and reduce the impact of waste on landfills.

Data security: protecting the data collected from waste sensors is crucial. Housing companies should implement robust data security measures to safeguard resident information and system integrity. Security features were taken into account in system design.

This study covers all other features, but route optimization remains outside the scope of study, since route optimization is under logistic company’s control and this study has focus on housing company.

2. Materials and methods

This case study presents results on a follow-up study for real-time monitoring of waste infra and related optimization of waste logistics. Study was carried out for a housing company in Espoo, Finland for twelve months during 2022-2023. Housing Company Waste Infra consists of 7 deep waste collection containers for separated waste fractions (mixed waste, carton, paper, plastic packages, biowaste, metal, glass) (HSY, 2018; Toivari, 2021). Housing company consists of 33 apartments with 103 residents, out of which 40 children. Monitoring was carried out using Wastebook Jaete cloud service and Jaete microradar sensors. The system produces real-time data on container fill level and temperature. The IoT devices are connected to cloud service sending measurement data every 2 hours. System can be integrated with route optimization systems through API but in this case, Wastebook’s sensor data was used only for monitoring (HSY, 2021; HSY, 2022).

First part of the study, 3 months, consisted of fill level monitoring. Bins were emptied according to previously existing weekly routine according to Table 1. For mixed waste fill level was 39% on average, with remarkable variation between different weeks. Average fill level for carton was 81% and for plastics 69% (Fig. 1).

In the second part of the study, updated emptying routines for deep collection bin emptying were implemented, according to monitoring results. New routines included a twice-longer collection interval for mixed waste bin. Two bins (metal, glass) were emptied with 16 weeks interval due to waste management regulations, even when the fill level was not reaching target value (Karnchanawong and Suriyanon, 2011).

Third part of the study consisted on cost saving estimations for the Housing Company, with payback time/SaaS-service calculations. Based on the results, annual costs for the waste management for housing company decreased 21% with new practices.

3. Results and discussion

According to monitoring results, new routines were planned in collaboration with housing company. Existing waste management regulations set limitations on expanding emptying intervals, which prevented optimization for certain fractions (Ministry of the Environment, 2021). Degree of filling for glass waste and biowastes remained low also after the updated routine due to legislatory guidelines. Figure 2 presents combined results for mixed waste surface level monitoring and weight.

Total cost saving for the housing company as direct savings from logistics was 21%. This does not include monitoring costs, which in this case required bigger investment in the first year and run with SaaS -fee with annual agreements. Despite the required investment, financial gain through decreased waste logistic costs was gained already during first year of operation (Official Statistics of Finland, 2018).

During the case study full integration of waste data system with local waste management company's ERP and route optimization systems was not available. Full implementation of smart waste management chain reaching all operations from real time fill level monitoring to route optimization and dynamic collection intervals would allow further improvements in emptying routines (Metsäteollisuus Ry, 2021). In case study's housing company, the system integration would have further reduced the amount of waste collections thus lowering the emptying fees even more. Total accumulation for different waste fractions is shown at Table 2.

Also, better situational awareness on waste fractions and related waste management costs can affect significantly in customer behaviour, especially in case housing company is facing difficulties with customers willingness to recycle. In the studied housing company, recycling rate remained according to Table 3 between 45-63. As noticeable detail, paper was not collected at the housing company but at the nearby public station. Amount of recycled paper was not monitored, but assumable it increases overall recycling rate according to nationally measured records. Measured amount of recycled paper and carton waste reached 94% in Finland according to 2021 figures, whereas European average was 75%.

During the case study there was also a transport industry strike that lasted one week in February 2022 causing widespread littering problems and overflowing waste bins in Helsinki Metropolitan area. There were no overfilling situations in housing company. The advantage of deep collection containers is the form and capacity which enable waste to become more compacted and thus capable of containing more waste. The benefits of fill level monitoring and collection optimization with the data thereof are emphasized in deep collection containers; the expenses of one emptying are considerable compared to a wheelie bin collection. The costs of monitoring system are thus amortized relatively quickly.

Table 1. Waste container types, capacities and collection intervals of Housing company Lumitähti

Waste type	*Mixed waste*	*Carton*	*Plastic*	*Bio waste*	*Paper*	*Glass*	*Metal*
Container capacity	5 m^3	5 m^3	2.4 m^3	1 m^3	2.4 m^3	1.6 m^3	1.6 m^3
Collection interval at the start	1 week	1 week	1 week	2 weeks	na	8 weeks	8 weeks
Collection interval after monitoring	2 weeks	1 week	1 week	2 weeks	Varied from 1 to 2 months*	16 weeks	16 weeks
Monitoring period	1.8.2022-31.7.2023	1.8.2022-31.7.2023	1.8.2022-31.7.2023	1.8.2022-31.7.2023	1.8.2022-31.7.2023	1.8.2022-31.7.2023	1.8.2022-31.7.202 3

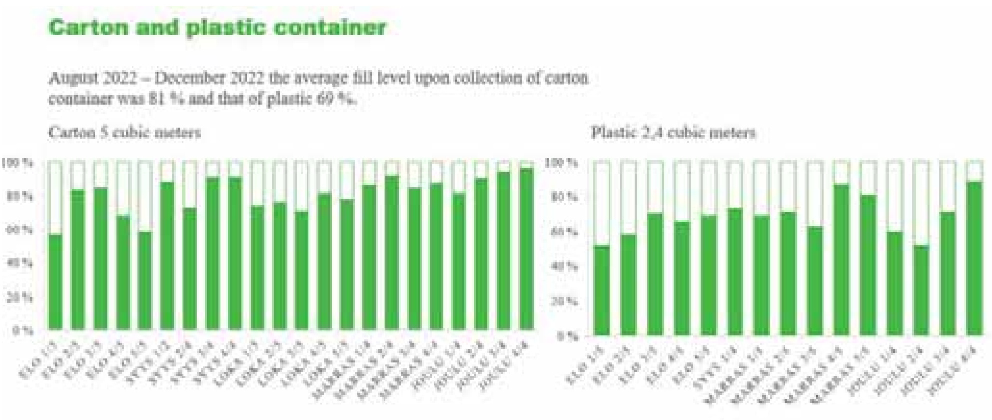

Fig. 1. Filling rates for plastic and carton containers during first part of the study; fill level data is missing in September and October due to change of sensor in plastic container

Table 2. Fill level, weight and temperature collection intervals of Housing company Lumitähti

	Collections 1.8.2022-31.7.2023	*Avg fill level upon collection (%)*	*Total waste accumulation 1.8.2022-30.4.2023 (kg)*	*Avg weight upon collection (kg)*	*Min °C*	*Max °C*
Mixed waste	31	63	5.315	259	-7.2	49.9
Carton	53	77	2.048	50	-8.6	44.5
Plastic	51	69	836	21.4	-6.1	48.1
Bio waste	25	48	2.980	157	-4.9	45.3
Glass	4	37	303	101	-8.3	48.5
Metal	4	52	109	36.3	-9	56.6
Paper	7	69	na	na	-8.2	50.4

Table 3. Recycling rate and mixed waste accumulation per person

	Mixed waste (kg)	*Total waste (kg)*	*Plastic, bio waste, carton, glass & metal (%)*	*Mixed waste per person (kg)*
Apr-23	896	1629	45	8.7
Mar-23	540	1256	57	5.2
Feb-23	530	1131	53	5.1
Jan-23	670	1358	51	6.5
Dec-22	715	1289	45	6.9
Nov-22	590	1241	52	5.7
Oct-22	475	1295	63	4.6
Sep-22	925	1602	42	9.0
Aug-22	760	1574	52	7.4

(a) (b)

Fig. 2. Degree of filling and weight for mixed waste container during test periods: (a) surface level monitoring; (b) combined weight and surface level monitoring

Concerning biowaste, further optimization of collection intervals and similar prevention of odor appearance due to decomposting could be reached by aerated bins and plastic bags for biowaste collection. In this study traditional sealed bins and plastic bags for biowaste were used. The aerated bins are feasible for detached houses but also for small housing co-operatives and the system works both in urban and dispersed settlements. With aerated bins, there is a possibility of longer collection intervals when compared to the sealed bins due to controlled start of composting process instead of anaerobic decomposition. Longer intervals between collection would further reduce transportation with collection vehicles. The aerated bins and paper bags are evaluated to work in a cold climate better than the sealed bins and plastic bags, as when breathable paper bags are used, the bags are not stuck on the inner surface of the bin, which would make the collection easier. In previous case study, collection of the biowaste with aerated bins and paper bags was evaluated to work well in the case of aerated bins, as the light weight of the bins increase the collection ergonomics and safety. In Nordic conditions, decomposition processes and related odor appearance is not appearing due to low temperatures during wintertime. In winter, the organic waste stored outdoor would freeze and a significantly longer collection interval could be used. Follow-up data for biowaste storing temperatures will support further optimization for winter-time biowaste freezing vs. extended collection interval.

5. Conclusion

This case study for a single housing company showed clear possibilities to update maintenance routines into more cost efficient and environmentally sustainable manner. The study also indicates that as the recycling rate increases or is already high, the amount of mixed waste is reduced hence requiring a review of waste collection routines. As a result of fill level data project the housing company reduced the collections of mixed waste from scheduled 52 collections to 31 during the monitoring period.

Results between different housing companies with differing customer profiles can vary a lot and routines between different housing companies can follow remarkably different patterns, which means that results from one housing company can't be generalized. Case study housing company had a very strong customer profile of a family with children, which presumably has a connection with waste fractions such as diapers. Still the overall amount of mixed waste per person in the housing company was relatively low varying monthly from 4.6 kg to 9.0 kg compared with the monthly average of 11 kg in the Helsinki Metropolitan area.

Total cost saving for the housing company as direct savings from logistics was 21%. This does not include monitoring costs, which in this case required bigger investment in the first year and run with SaaS -fee with annual agreements. Despite the required investment, financial gain through decreased waste logistic costs was gained already during first year of operation.

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A SURVEY ON THE CIRCULAR ECONOMY IN THE SICILIAN AGRI-FOOD SECTOR*

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Abstract

The transition to a circular economy represents an interesting opportunity for Sicily, as it allows the island to exploit its resources in a sustainable way while promoting economic development and environmental protection. Thanks to its wealth of natural and agricultural resources, the island plays a crucial role in the transition towards a circular model. Through the adoption of strategies and business models oriented towards the circular economy, Sicilian companies can optimize the use of resources, reduce waste and promote the creation of long-term value, transforming environmental challenges into opportunities for growth and prosperity. The paper aims to present the current business panorama of eastern Sicily and to provide the results deriving from a survey on the diffusion of the circular economy which involved the agri-food sector. In particular, examples of circular economy on the island are first presented, secondly, the research methodology adopted is described, based on a specific questionnaire addressed to various supply chains in the Sicilian food sector: finally, the results and suggestions aimed at businesses are presented.

Keywords: agricultural sector, circular economy, decision making, performance indicators, renewable resources, sustainability

1. Introduction

The food production and consumption system is the sector that most clearly shows the impacts and contradictions of the linear economic model. Food production has contributed to

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the crossing of as many as four thresholds that determine planetary limits, that is, those values within which humanity must move to maintain a state of equilibrium of the biophysical systems that support its existence (Rockström et al, 2009). Climate change, loss of biodiversity, alterations to the nitrogen and phosphorus cycle, and changes in land use are respectively related to an agriculture that: produces about one-third of greenhouse gas emissions (IPCC, 2013); consumes 69% of water resources globally (Fassio and Tecco, 2018); uses between 10 and 30% of the amount of energy consumed in industrialized countries (Cuéllar and Webber, 2010); and contributes heavily to chemical pollution.

The current food production model is based on intensive production, monocultures and reckless use of manure and fertilizers. Carbon dioxide, methane and nitrous oxide are emitted directly and indirectly throughout the value chain of agri-food supply chains.

According to a study published in March 2021 in Nature Food, in 2015, CO_2 emissions related to food systems reached 18 billion tons, accounting for 1/3 of the total (34%), and of these 29% come from distribution, processing, consumption and end-of-life (Crippa et al, 2021). With reference to packaging, the emissions produced by the food sector, reach nearly 1 billion tons of CO_2 (Gentili and Zampetti, 2021). At the same time, primary activity is also one of the economic sectors most exposed to the climate change already taking place: scarcity of water resources, alterations in rainfall regimes, and frequency and intensity of extreme weather phenomena represent conditions to which the agribusiness sector must adapt quickly. Studies conducted by the FAO show that, due to severe pressure on natural habitats, 75% of the varieties of agricultural crops have been lost with severe repercussions on the variety of food diets worldwide (Fassio and Tecco, 2018).

The objective of this paper is to illustrate the potential of a transition from the current linear economic model, in which resources are used as if they were unlimited, to a circular model, which is essential considering growing environmental issues.

To this end, a survey was carried out to take a snapshot of the current situation of the Sicilian agribusiness ecosystem. Based on the responses obtained, some key suggestions emerged that could help promote relational networks, best practices and sustainable styles for the corporate world.

2. Materials and methods

The industrial revolution that took place at the turn of the eighteenth and early nineteenth centuries gave rise to the current model of economic growth, termed "linear" and organized according to a "take, make and dispose" model (Esposito et al, 2015). In accordance with the linear economy model, firms extract materials, employ energy and labor to manufacture a product and sell it to the final consumer, who disposes of it when it no longer serves its purpose.

The linear economic system results in significant losses along the value chain and does not take into account environmental impact. This model, based on the inexhaustibility of natural resources, appears less and less sustainable today. It is estimated that by 2030 the world's population will reach 9 billion individuals and that about three billion will experience substantial increases in disposable income (Musella and Verneau, 2017). On the other hand, the amount of raw materials, and in particular mineral resources, fossil fuels and biomass, extracted in 1900, amounting to 6 billion tons per year, has grown to 60 billion in 2010, and is estimated to grow to 140 billion tons in 2050, which is more than double current consumption (Krausmann et al, 2009). Strong population growth, increasing wealth and per capita income could lead to an imbalance between demand and availability of raw materials, and in particular energy resources.

The limits of that growth model began to appear from the 1970s: the 1973 oil shock brought about a crisis in the model of economic development experienced until then, the so-called "golden age" of the economy (1945-1973), characterized by an extraordinary acceleration of industrial production and consumption. The problems associated with that model began to emerge: soil and water pollution, the emission of greenhouse gases and the resulting climate change, and the exploitation of limited natural resources (Codovini, 2020).

In 1972, a group of scholars gathered in the "Club of Rome" published a report entitled "The Limits to Growth," which stated that current levels of production and consumption would lead to the depletion of natural resources in the short term (Lacy et al, 2016). In the same year, the first world conference on the environment was held, concluding with the Stockholm Declaration, which clearly recognized the need for all states to protect the environment and natural resources (Birnie et Boyle, 1993).

In 1979, with the Geneva Conference, a climate program (World Climate Program) was launched, which had the merit of passing a Protocol on transboundary pollution (Nucera, 2011). At the same time, there was the emergence of a new discipline, environmental ethics, which addressed environmental issues arising from human action with the tool "bioethics". This discipline radically redefined the anthropocentric model, for which nature has no value in itself, but only with respect to human needs, and began to question man's moral obligations to nature (Codovini, 2020).

The transition to a circular economy represents an interesting opportunity for Sicily, as it allows the island to sustainably exploit its resources while promoting economic development and environmental protection (Scaffidi, 2022). Due to its wealth of natural and agricultural resources, the island assumes a crucial role in the transition to a circular model. Through the adoption of circular economy-oriented strategies and business models, Sicilian companies can optimize resource use, reduce waste and promote long-term value creation, turning environmental challenges into opportunities for growth and prosperity (Bressanelli et al, 2019).

This is the context for the initiative to monitor the development of the circular economy in Sicily, to assess its impacts on the evolution of business models and employment, as well as the creation of new professional figures. The survey aims to take a snapshot of the current situation of business activity in order to promote relational networks, best practices and sustainable styles for the corporate world. It is aimed at companies in the Sicilian agribusiness ecosystem, and in particular in eastern Sicily, and involves voluntary participation. The survey is conducted through the completion of a questionnaire consisting of 20 questions aimed at framing the company, ascertaining the existence of implemented best practices and professional figures involved in environmental sustainability and the circular economy, and quantifying current environmental impacts.

The layout of the questionnaire (Table 1) was divided into four thematic macro-areas:

1.General information (1-6). This information is essential to frame the size of the company in terms of staff and turnover and to understand its sector.

2.Sustainability indicators (7-11). In the second macro-area, questions were included in relation to several activities that denote a particular sensitivity to sustainability issues and, some more specifically, the circular economy. For example, companies were asked to indicate voluntary certifications acquired and the presence of professional figures involved in sustainability and circularity.

3.Future expectations (12-13). The third macro-area of the questionnaire explores the future goals that the surveyed entities set for themselves. Specifically, companies were asked if they plan to acquire certifications in the circular economy and what will be the impacts of a transition to a regenerative economy in their business sector.

4.Approach to circularity (14-20). The fourth and final macro topic area provides insight into the main circular economy practices already implemented by the company.

Companies are asked to describe the company's current waste and residue management methodology, indicate obstacles and/or barriers encountered in the application of circular economy within their production process, as well as tools that can support the ecological transition process in their company.

Therefore, the questionnaire analysis offers a first overview of the degree of awareness and diffusion of circular economy in the Sicilian agribusiness reality.

Table 1. Questionnaire

1. Business name:
2. Role of the survey filler:
3. Core business: □ Manufacturing □ Textile and clothing □ Public services □ Consulting services □ Chemical □ Pharmaceutical □ Construction □ Electronics □ Food processing and distribution □ Tourism □ Waste management □ Other
4. Number of employees: □ < 10 □ between 11 and 50 □ between 51 and 250 □ > 250
5. Headquarters:
6. Average annual revenue: □ < € 2M □ between € 2M and € 10M □ > € 10M
7. Voluntary certifications acquired: □ ISO 9001 □ ISO14001 □ EMAS □ ISO 37001 □ ISO 26000 □ ISO 45001 □ None □ Other
8. It there a professional figure in the company that deals with environmental sustainability and circular economy? □ Yes □ No
9. If yes, which one? □ Comunication manager □ Environmental sustainability manager □ HSE manager

☐ Human resources ☐ Other:
10. Has your company undertaken any projects inherent to the circular economy in the past 2 years or is it planning to do so in the near future? ☐ Yes o Which areas have been or will be affected by the project(s)? ____ ☐ No o Why?
11. Have training actions been implemented to share circular economy concepts with human resources? ☐ Yes ☐ No
12. Are there any plans to acquire voluntary certifications in the circular economy field over the next 3 years? ☐ Yes ☐ No
13. In your opinion, what will be the impacts of circular economy on your company's core business? ☐ Reducing waste of resources ☐ Marketing and comunication ☐ Improvement of corporate reputation ☐ Relationship with employees ☐ Customer relationship ☐ Other
14. Describe a best practice already implemented in your company.
15. Describe the current methodology for waste management applied in your company.
16. Your company currently quantifies its environmental impacts on ☐ Air ☐ Soil ☐ Water resources ☐ Energy consumption ☐ Natural resources consumption
17. Does your company currently offset natural resources consumption and business impacts? ☐ Yes o How? ☐ No
18. In your opinion, what is the barrier or obstacle to the implementation of circular economy in your production process?
19. What tools and opportunities can support the green transition process in your company?
20. Would you be interested in receiving the results of the survey and participating in educational activities on circular economy? ☐ Yes ☐ No

3. Results and discussion

This paper presents the results that emerged from a survey conducted on agribusinesses in eastern Sicily, aimed at assessing the degree of diffusion of the circular economy. The sample, to which the questionnaire was administered, consisted of 10 companies. As the data collected highlights, the heterogeneity of the companies nevertheless found unanimous responses in some cases, while in others it amplified the differences especially in terms of the performance of activities and planning of future expectations (Gatto and Lopez, 2019).

The first thematic macro-area (1-6), which is purely descriptive, aims to gather information on companies' characteristics; although the companies interviewed remain anonymous, a distinction by business sector, number of employees and average annual turnover is of interest. The second macro area (7-11) aims to investigate the efforts already implemented by companies on environmental sustainability and circular economy. In particular, companies were asked to indicate voluntary certifications acquired, the presence of professional figures dealing with sustainability and circularity, medium- to long-term projects inherent to the circular economy, and the activation of training actions aimed at their employees, designed to share the principles of the circular economy.

All of the companies surveyed have at least one certification, which denotes a particular sensitivity to issues of environmental sustainability and food safety (Fig. 1). Some of the certifications mentioned in the "Other" category include: BRC Food certification, ISO 50001, ISO 22000, IFS Food, Viva, SOStain. In almost all of the cases examined, there was not any professional figure with specific skills in the field of environmental and social sustainability. Only one figure, the Chief Sustainability Officer, responded positively to the question. All of the companies surveyed have taken or intend to take actions to limit their environmental impacts in the next 2 years. The third macro area (12-13) analyzes the future prospects that the surveyed companies envision. Specifically, companies were asked whether they plan to acquire certifications in the circular economy and what the impacts of a transition to a regenerative economy will be in their business sector (Fig. 2). All of the agribusinesses surveyed plan to acquire additional certifications in the circular economy.

Regarding the impacts of a transition to a regenerative economy, all of the companies surveyed believe that it can lead them to limit the waste of resources; 90% of them surveyed believe it can lead them to improve their reputation and, given the growing consumer awareness of environmental issues, strengthen their relationship with their customers.

The fourth macro area (14-20) analyzes the circular approach implemented by the agribusiness ecosystem surveyed, forming the core of the questionnaire.

With reference to the best practices implemented, an extensive photovoltaic system, capable of powering the production plant, guaranteeing the production site a flow for energy sustenance entirely self-generated from renewable sources; a complex system of purification of processing water, reused to irrigate the company's vegetable garden, are mentioned; packaging that is fully compostable or made of recyclable materials to allow proper disposal of packaging; a "just in time" production system that produces small quantities based on sales, i.e., the quantity ordered in advance, and thus allows the company not to create surplus or leftover stock and to minimize waste; reuse of a food product that is slightly overcooked at the end of the cooking process as a semi-finished product for the production of another product, considering it illogical to discard a good, fresh product for aesthetic reasons; adoption of sustainable agricultural practices, such as organic farming and the rational use of pesticides and fertilizers, which allow the company to preserve soil fertility, protect biodiversity and reduce pollution from chemicals.

All of the companies surveyed believe they are impacting the environment due to their energy consumption (Fig. 3). Although there are some barriers, including lack of financial resources and lengthy processes to acquire certifications, all the companies surveyed interpret the circular economy as a great opportunity and have undertaken and/or planned projects aimed at implementing the circular economy. The concluding question, to which all the companies surveyed answered in the affirmative, concludes the survey on a positive note, demonstrating a growing interest on the part of the Sicilian business ecosystem in the circular economy and its applications.

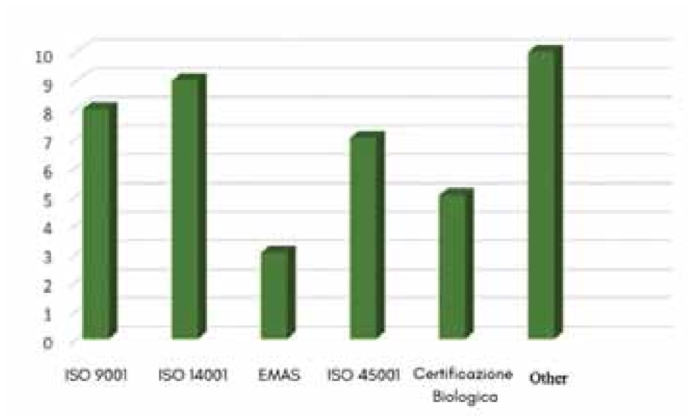

Fig. 1. Voluntary certifications acquired

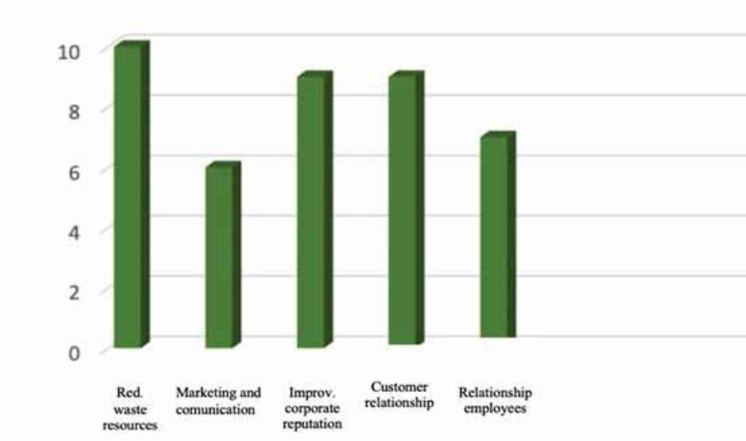

Fig. 2. Impacts of a transition to a regenerative economy

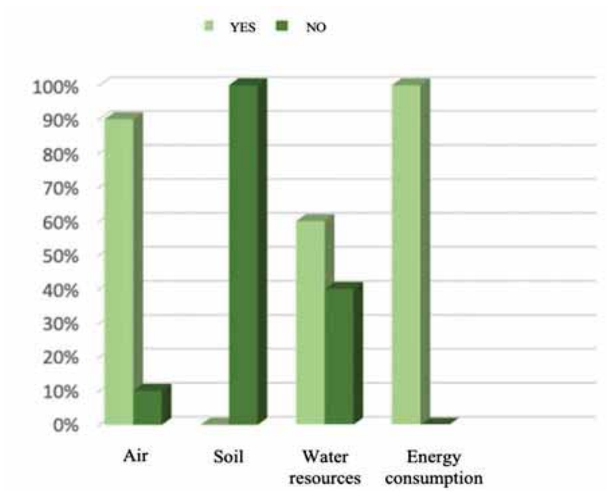

Fig. 3. Environmental impacts

The companies interviewed constitute a very heterogeneous set both in terms of organizational structure and dedicated staff, as well as in relation to the circularity practices adopted. This heterogeneity is evident because the companies belong to different market sectors and are distinguished by their business histories, which differ in terms of time; in fact, some of them were founded a few years ago or have recently started a transition to the circular economy, while others are long-lived companies on both fronts. Moreover, these companies possess entrepreneurial projects with divergent perspectives and goals. Despite these differences, the responses obtained were more than positive and, in some cases, showed particularly significant trends.

The survey of Sicilian agribusinesses on environmental sustainability and circular economy provided valuable information on possible improvements that can be made by companies. Based on the responses obtained, some key suggestions emerged that could help promote circular economy principles. First and foremost, the priority aspect to consider is resource optimization. Companies should adopt practices that aim to minimize waste by implementing more efficient production processes and recycling materials. The introduction of advanced technologies and automation can help optimize processes and reduce environmental impact. In addition, the survey highlighted the importance of promoting sustainable supply chains. Agribusinesses should forge partnerships with suppliers who adopt sustainable practices such as, for example, organic farming and responsible use of water resources, while ensuring food quality for their customers.

Another key aspect concerns waste management. Companies in the industry should adopt policies on waste reduction, recycling and composting, helping to reduce their environmental impact. Finally, the survey emphasized the importance of staff training and awareness. It is important for companies to invest in training their employees in order to promote environmental and social awareness and develop specific circular economy skills. This will result in all members of the organization being involved in the adoption of sustainable practices and actively contributing to the achievement of corporate goals.

It is clear that the current system, based on a rigidly linear logic, does not work, and that a shift to a circular and regenerative economy would bring enormous benefits, enabling businesses to reduce their dependence on foreign countries while contributing to the achievement of Sustainable Development Goals 12 and 13 (SDGs), which are of crucial importance to humanity and the planet (Oliveri et al., 2022). Specifically, Goal 12, "Responsible Consumption," aims to halve global food waste, make the food supply chain more efficient, significantly decrease the amount of waste produced and improve its management; Goal 13, "Combating Climate Change," aims to strengthen resilience and capacity to manage environmental disasters affecting Planet Earth (Falzarano, 2020).

4. Concluding remarks

In Sicily, the implementation of the circular economy is still in its infancy. Despite the bureaucratic complications, the regulatory environment characterized by complex and rigid rules and the lack of or poor knowledge of the topic on the part of many factors in the sector, there are many virtuous cases in the agri-food sector, which has long been engaged on the front of reducing food waste and, for some years now, on initiatives to reduce the use of packaging. In fact, some Sicilian companies can enjoy the title of "pioneers" or "forerunners". Being ahead of the curve, especially in the corporate world, can be a crucial advantage over the competition and thus represent a huge opportunity.

The survey conducted on the Sicilian business ecosystem on environmental sustainability and circular economy provided valuable information on possible improvements that can be made by companies, contributing to the promotion of circular economy principles and relational networks between virtuous companies, institutions and civil society.

It also found an awareness on the part of companies with reference to the benefits of a transition to a regenerative economy, including reduced resource waste, improved corporate reputation and, considering consumers' growing awareness of environmental issues, improved customer relations.

As a major contributor to environmental degradation, the agri-food sector can be transformed into a valuable ally in combating climate change and creating an economy that respects the natural balance. Therefore, it is necessary to rethink the agribusiness sector that provides nutritious, healthy and accessible diets for all while fostering the ecological transition, following the path set by the European Union, from field to table.

When talking about sustainability, green reconversion and, especially, circular economy, one must start from an inescapable assumption: Sicily will be able to achieve the expected results only if it succeeds in making this transition systemic and transversal, involving as much as possible the economic and productive system as a whole, but also institutions and citizens. Only through a collective commitment will it be possible to take full advantage of the opportunities offered by the circular economy, promote the region's sustainable development and preserve the island's natural resources.

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THE ECOLOGY OF FRANCESCO: SUSTAINABILITY REPORT OF "THE ECONOMY OF FRANCESCO" GLOBAL EVENT*

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Abstract

The goal is to describe the methodology and the results obtained from the Carbon Footprint (CF) analysis of the event "The Economy of Francesco 2022". To achieve this goal, the technical standards UNI EN ISO 14040:2021, UNI EN ISO 14064-1:2019 and UNI EN ISO 14067:2018 were used. Starting from the activity data collected and using the IPCC algorithm, the CF of the event was calculated equal to 27 tons CO_2 eq, which outlined a remarkable amount of emissions avoided thanks to the decisions taken. In percentage terms, 58.73% of the impact is attributable to materials, 0.15% to electricity, 8.34% to waste and 32.75% to overnight stays. From this it emerges that the total tons CO_2 eq are mostly attributable to the materials used followed by overnight stays and waste. Finally, from the data collected on the waste produced, it can be seen that the overall percentage rate of waste differentiation is greater than 90%, of which 75% is the organic fraction sent for composting.

Keywords: Assisi, carbon footprint, environmental impact, integral ecology

1. Introduction

The organization of an event occurs within economic, environmental, and social contexts specifically selected for its successful execution, offering something unique and continually evolving. Simultaneously, an event generates various impacts, such as those related to material procurement, electricity consumption, and waste production, which are

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inevitable during the event's setup, execution, and dismantling phases. It is crucial, during the event's planning and subsequent phases, to declare the commitments, objectives, and actions that the organizing committee intends to implement to enhance the event's environmental and socio-economic performance throughout its life cycle (Holmes et al., 2015). Therefore, it is essential to adopt recognized and replicable methodologies for event management to quantify and communicate the generated impacts, providing a benchmark and comparison in case of future repetitions. The organization of an event must, therefore, focus on maximizing positive impacts (benefits) while minimizing and mitigating the negative ones. In this regard, identifying and selecting feasible environmental, economic, and social solutions with genuine added value is crucial (Laing and Frost, 2010).

The objective is to present the results obtained from the actions and sustainable management of the event "The Economy of Francesco," held in Assisi from 22 to 24 September 2022 (Francesco Ecology, 2022; Pope Francesco, 2019). The aim is to quantify both the emissions generated (tons CO_2 eq) during the event and the avoided ones, thanks to the planned mitigation actions.

3. Materials and methods

The methodology used to calculate the event's emissions follow to the UNI EN ISO 14064-1, 2019; UNI EN ISO 14067, 2018; UNI EN ISO 14069, 2017 standards. The system boundaries encompassed all processes and materials considered in the impact assessment, with this study specifying the period from 21 September 2022 to 24 September as the timeframe. The functional unit, representing all inputs and outputs, was defined as the event itself.

Carbon footprint (CF) calculations were conducted proactively to anticipate the expected impact and identify mitigation measures. This allowed us to ascertain the actual emissions generated and the impact mitigated (UNEP, 2009). The data used for quantification fell into two categories:

- Primary data: gathered through interviews, questionnaires, and supporting documentation (e.g., invoices). These data points were collected before, during (e.g., recycling, meals, overnight stays), and post-event (covering energy and water consumption).
- Secondary data: sourced from Ecoinvent, a scientifically validated database.

Certain data, such as participant travel to and within Assisi and information related to dinners not provided by event organizers, were excluded from the study due to the organizers' inability to control and monitor them. Including assumptions and hypotheses regarding these data would risk inaccurate overall reporting. Thus, we decla--re that these data will not be presented in this document. The collected data (inventory) underwent further processing using the IPCC calculation method (2021). The chosen indicator was the Global Warming Potential (GWP) index over a 100-year period (IPCC, 2021).

4. Results and discussion

The results were divided into the following cost centers: material, electricity, water, waste, and overnight stays. The matter includes what concerned the fittings, the use of plastics and bottles, gadgets (pen, notebook, backpack). For the preparation of the event, the use of reusable wooden pallets was chosen, which brought an environmental benefit when compared with the emissions generated using traditional panels (Schlenker et al., 2010) (Table 1). The wooden pallets (PEFC certified) reused following the event generated a saving of 109.5658 tons CO_2 eq compared to traditional panels (Table 1). Table 2 displays the results achieved through the utilization of biodegradable and compostable materials in comparison to the outcomes stemming from the use of conventional plastics. An exception is represented by the cardboard box, which has been disposed of in the paper recycling chain. Products crafted from biodegradable and compostable materials contribute to lower carbon footprints (CF) than their traditional counterparts, offering an environmental performance advantage for the event (UNI EN 13432, 2002). Furthermore, the composted material contributes to soil redevelopment, which is an increasingly valuable resource, and the performance advantage is also logistical, because it facilitates separate waste collection (Barthe et al., 2017).

Table 3 illustrates the advantages stemming from the utilization of reusable bottles. The environmental burdens associated with the production of reusable bottles are amortized and distributed based on the bottle's useful lifespan. Likewise, the impact of PET bottles was assessed, considering the estimated average daily water consumption.

Table 4 presents the outcomes achieved through the adoption of a kit comprising a sustainable notebook made of FSC-certified paper, a pen crafted from biodegradable and compostable materials, and a cotton backpack, in comparison to those potentially obtained through traditional alternatives. Once again, the corresponding savings in terms of tons CO_2 eq, when compared to traditional options, are provided.

Table 1. Comparison between traditional pallet emissions and ones related to the event

Material	*Unit of measure*	*Value*
Pallet panels	tons CO_2 eq	7.4717
Traditional Panels	tons CO_2 eq	117.0375
Total CO_2 not emitted	tons CO_2 eq	-109.5658

Table 2. Comparison between materials

Material	*Unit of measure*	*Biodegradable*	*Traditional*	*Saving*
Silverware	tons CO_2 eq	0.1150	0.1850	-0.07
Glasses	tons CO_2 eq	0.6405	1.2820	-0.6415
Palettes	tons CO_2 eq	0.0050	0.0099	-0.0049
Food box	tons CO_2 eq	4.1101	5.0358	-0.9257
		Recyclable		
Cardboard box	tons CO_2 eq	0.3516	0.3516	0
Total	tons CO_2 eq	5.2222	6.8643	-1.6421

Table 3. Comparison between reusable and traditional disposable PET bottles

Material	*Unit of measure (UoM)*	*Value*
Bottles 500ml	tons CO_2 eq	0.0017
Pet bottles 500ml	tons CO_2 eq	0.0919
Total CO_2 not emitted	tons CO_2 eq	-0.0902

Table 4. Comparison between the supplied sustainable kit and a traditional one

	UoM	*BIO/FSC/Cotton*	*Traditional option*	*Saving*
Quill	tons CO_2 eq	0.0134	0.0164	-0.0030
Notebook	tons CO_2 eq	0.0449	0.0493	-0.0045
Backpack	tons CO_2 eq	0.2531	3.3572	-3.1041
Total	tons CO_2 eq	0.3114	3.4229	-3.1115

Table 5 shows the impact deriving from the food products used in the preparation of lunches, which we recall coming from companies that operate on assets confiscated from organized crime, on the seismic crater of Umbria and from companies settled in the local area. The number of meals consumed was 3437. It is worth mentioning that a further element of emission control is also the decision not to implement meat in meals preparation. Table 6 shows the results related to the separate collection of the waste generated during the event, performed with consequent controlled management, according to the type of waste, and compared with the results of a hypothetical uncontrolled management. Table 7 shows the benefits deriving from overnight stays performed in accommodation facilities such as hostels and hospitality houses. As shown in Table 8, a monitoring campaign has been launched focusing at electricity and water consumption. At the time of definition and implementation of the event, it was not possible to proceed with mitigation actions (e.g., 100% use of renewable energy) since the activities took place in spaces where there were already active utilities beyond the control of the organizers. The CF recorded for the event is 27.20 Ton CO_2eq with the following percentage contribution, as shown in Table 9. Below is a summary of the expected emissions and those actually produced with regard to the materials used, electricity, transport, water, waste and the overnight stays of the young people who attended the event, and all the staff involved (Table 10).

The final results of the calculated impact are definitely lower than the forecasts. This was possible thanks to an efficient use of resources within the premises used for the event. Particular importance was given to energy saving, favored by the reduced use of air conditioning systems and the choice of accommodation facilities other than hotels, for welcoming the participants. In addition to representing an advantage from an environmental point of view, this has made possible to obtain positive social implications, related to the establishment of connections between the participants (WCED, 1987).

Therefore, alternative solutions were studied with the aim of reducing and controlling the traditional impacts of the event. The areas of greatest intervention were therefore related to the choice of materials and suppliers, waste management and participants welcoming. These areas are also those in which the organization has the greatest control and decision power. The following table (Table 11) highlights the reduction of the impact, calculated in advance, compared to the adoption of traditional measures, or commonly adopted before a sustainability study. The final result therefore made it possible to highlight and verify that the mitigation actions and preventive measures, adopted upstream by the organizers, have actually led to a reduced impact compared to traditional practices and solutions.

Table 5. Carbon Footprint (CF) linked to catering

	UoM	*Value*
Traditional meal	tons CO_2 eq	4.1930
Sustainable meal	tons CO_2 eq	2.9733
Total CO_2 not emitted	tons CO_2 eq	1.2197

Table 6. CF linked to waste

	UoM	*Value*
Waste collected separately	tons CO_2 eq	2.2713
Waste not collected separately	tons CO_2 eq	2.6792
Total CO_2 not emitted	tons CO_2 eq	-0.4079

Table 7. CF linked to overnight stays

	UoM	*Value*
Hospitality houses	tons CO_2 eq	8.9120
Hotels	tons CO_2 eq	12.6717
Total CO_2 not emitted	tons CO_2 eq	-3.7597

Table 8. CF linked to electricity and water consumption

	UoM	*Value*
Electric energy	tons CO_2 eq	0.04150
Water	tons CO_2 eq	0.00003

Table 9. Total CF of the event

Cost centers	*UoM*	*Value*	*Value (%)*
Matter	tons CO_2 eq	15.98018	58.7398%
Electric energy	tons CO_2 eq	0.04150	0.1525%
Water	tons CO_2 eq	0.00003	0.0001%
Waste	tons CO_2 eq	2.27130	8.3488%
Overnight stays	tons CO_2 eq	8.91201	32.7587%
Total	tons CO_2 eq	27.20502	100%

Table 10. Expected and actual emissions with calculation of Delta value

Cost centers	*UoM*	*Forecasted*	*Actual*	*Δ*
Matter	Ton CO_2eq	58.35892	15.98018	42.37874
Electricity	Ton CO_2eq	358.59000	0.04150	358.54850
Water	Ton CO_2eq	2.35399	0.00003	2.35396
Waste	Ton CO_2eq	6.44646	2.27130	4.17516
Overnight stays	Ton CO2eq	47.23960	8.91201	38.32759
Total	Ton CO_2eq	472.98898	27.20502	445.78395

Table 11. Traditional and actual emissions with calculation of Delta value

		Traditional	*Actual*	*Δ*
Matter	Ton CO_2eq	128.1867	15.98018	112.2065
Electricity	Ton CO_2eq	0.04150	0.04150	0.00000
Water	Ton CO_2eq	0.00003	0.00003	0.00000
Waste	Ton CO_2eq	2.6792	2.27130	0.4079
Overnight stays	Ton CO_2eq	12.6717	8.91201	3.7597
Total	Ton CO_2eq	143.5791	27.20502	116.3741

5. Concluding remarks

The study reveals that matter and overnight stays had the most significant impact on overall performance of the event considered (46% pallets, disposables 32%, catering 19%). 112 tons CO_2 eq were saved using compostable products and responsible supply chain; 3.7 tons CO_2 eq choosing local partners and low-consuming accommodation facilities.

Overall, the study highlights the importance of evaluating environmental performance from a carbon footprint perspective, using an environmental and economic cost centers inventory and modeling approaches based on calculation algorithms.

The findings can help define a methodology for identifying suitable mitigation solutions and serve as a reference for other events.

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WOOD WASTE VALORIZATION IN EUROPE: POLICY FRAMEWORK, CHALLENGES, AND DECISIONAL TOOLS*

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Abstract

Wood waste has immense value as it offers a plentiful and cost-effective resource for the production of materials and energy. Within Europe, approximately 46% of wood waste undergoes recycling to create particleboard, while the remaining portion is subjected to incineration. Numerous alternative approaches exist to enhance wood waste valorization but it is crucial to discern the most suitable treatment method based on the specific source matrix. Determining the optimal pathway for utilizing wood waste is challenging due to the complexity of its materials, which encompass pollutants, additives, contaminant materials, and varying chemical compositions. Moreover, the absence of a unified legislative framework at the European level adds to the complexity of managing wood waste effectively. The lack of standardized regulations and guidelines can hinder harmonized practices and impede efficient utilization of wood waste resources. Additionally, the absence of a precise decisional tool further exacerbates this issue, as stakeholders may face challenges in assessing and comparing different treatment options. The primary focus of this paper is to showcase the wood waste policy framework in Europe and identify crucial points for establishing an effective decisional tool that facilitates enhanced valorization of wood waste. By examining existing policies and practices, the paper aims to shed light on the critical issues faced by the wood waste management sector. Through this exploration, it seeks to contribute to the development of strategies and tools that can optimize wood waste utilization while promoting sustainability and circularity in the sector.

Keywords: policy framework, wood recovery, wood recycling, wood waste

1. Introduction

According to Eurostat waste statistics from 2020, the European Union (EU-27)

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generated a total of 48.28 Mt of wood waste (WW), with only 1.88 Mt classified as hazardous, accounting for 3.89%. The largest producers of WW within the EU were Germany, France, and Italy, with 13.32 Mt, 7.70 Mt, and 5.10 Mt, respectively (Eurostat, 2023). The largest sector producing WW is the "manufacturing" sector, which mainly includes the manufacture of wood and paper, accounting for 38.77% of the total. This is followed by the "water supply/waste management" sector at 21.71%, the "construction" sector at 17.79%, "households" at 10.58%, "services" at 8.93%, and other sectors at 2.22% (Eurostat, 2023). Considering that there will be an predicted shortfall of wood in Europe by 2030 (Mantau et al., 2010), the treatment and recycling of WW will play a central role in the coming years.

In 2020, 40.20 Mt of WW were treated, accounting for 83.26% of the total, while 8.08 Mt were not treated (16.74%). Among the treated WW, only 0.24 Mt were disposed of (0.60%), with the remaining 39.96 Mt (96.40%) being recovered. Of the recovered WW, 21.45 Mt were used for energy recovery, while 18.51 Mt (including 18.50 Mt for recycling) were utilized for recycling and backfilling, representing 53.36% and 46.04%, respectively. Considering the total WW production, disposal, energy recovery, and recycling-backfilling correspond to 0.50 %, 44.43 %, and 38.34 % respectively as shown in Fig. 1 (Eurostat, 2023).

Recycling WW poses a continuous challenge due to the variability of the materials involved, including fluctuating levels of cellulose, hemicellulose, and lignin; the presence of additives such as glues, varnishes, and paints; the existence of pollutants such as chlorine, fluorine, and heavy metals; and the presence of impurities like glass, plastics, and metals, among others.

The utilization of wood waste (WW) in the recycling process depends on the aforementioned factors, but it is significantly influenced by the policy framework within the European Union and individual member states. Currently, the most prevalent method for WW recovery involves incineration with energy recovery and the production of particleboard. The particleboard industry serves as an exemplary model of cascading WW utilization, having reached a scale-up situation. For instance, in Italy, particleboard is composed of approximately 95% of WW, the highest value in the EU (Vis et al., 2016). In other countries, significant percentages range from 50% to 70% in Belgium and Denmark, and from 15% to 30% in Spain, Germany, and France.

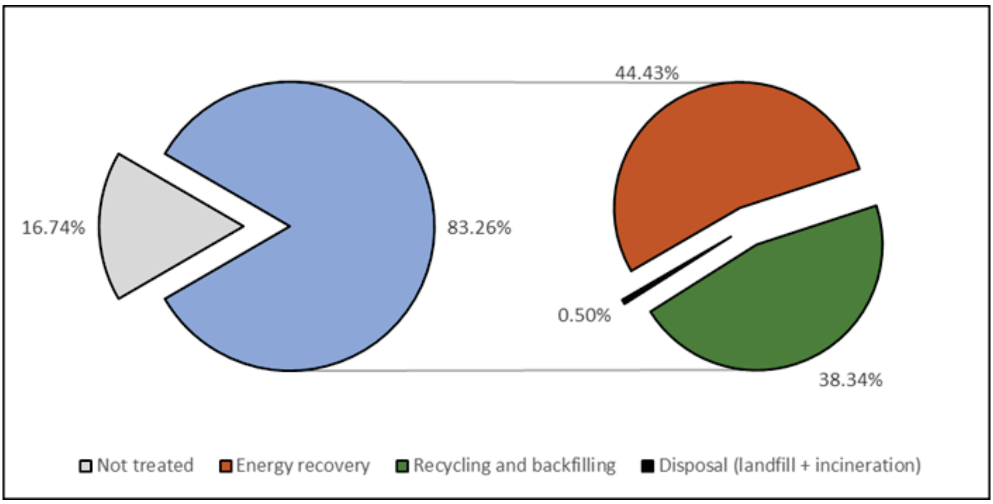

Fig. 1. Wood waste produced and treated in EU-27 in 2020

However, these figures could change with improved WW management and clearer decision-making tools. It is essential to develop new waste management solutions and technological advancements in other recovery fields. For instance, WW waste could also be utilized in pulping (Ahmed et al., 1998; Pazzaglia et al., 2023) and biorefineries (Deroubaix, 2014), but further research and development are necessary, especially in achieving high-quality WW or finding efficient decontamination methods (Besserer et al., 2021).

The purpose of this paper is to analyze the WW policy framework within the European Union in order to identify the primary critical issues that hinder the development of an effective decision-making tool for maximizing the valorization of wood waste. Additionally, we present a case study involving two WW collection companies located in Perugia, Italy, to illustrate the varying compositions of WW.

2. Material and methods

The analysis of the political-legislative context concerning wood waste is conducted through an examination of the primary sources of European law, namely directives and regulations. Following this, a brief overview of the main measures adopted by several European states is provided, with a focus on laws or proposals that delineate the classification of wood waste, followed by others that directly or indirectly contribute to wood waste recycling and, consequently, its cascading utilization.

Furthermore, a case study involving two waste management companies is presented. This analysis operates under the premise that the waste management sector exhibits significant variations from country to country and also at local level. However, there are also certain common functions and actors that are shared on a European scale as policy makers, industry, waste producers, research institutions, and of course waste management companies.

Given the dependence of the waste management features on the specific context, this paper focuses on two waste management companies located in Umbria, Italy. We provide data on the total amount of WW and the quantities of different WW categories, categorized by European Waste Catalogue codes (EWCc), in 2021. In Table 1, we offer a brief explanation of the EWCc codes found in the two companies, Gesenu Spa and Biondi Recuperi Ecologia srl. Furthermore, we present a pollutant analysis of the WW and compare it with the primary European references for pollutant limitations in WW recovery. The pollutant analysis data is provided by the companies.

Table 1. European waste catalogue codes identified within the two companies

Wood waste	***EWCc***	***Example***
Wooden packaging	15 01 03	Pallet, crates, boxes, cases, bins, reels, drums, load boards, skids, pallet collars and containers.
Sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04	03 01 05	Waste from wood processing and the production of panels and furniture
Waste bark and cork	03 01 01	Waste from wood processing and the production of panels and furniture: bark and cork scraps
Wood	17 02 01	Construction and demolition of wood
Wood other than that mentioned in 19 12 06	19 12 07	WW from wastes generated by waste treatment plants
Wood other than that mentioned in 20 01 37	20 01 38	Wood from municipal waste sorting
Biodegradable waste	20 02 01	Waste produced by gardens and parks (e.g., grass cuttings and branches)

3. Results and discussion

In Europe the main laws referring WW are the Waste Framework Directive (Directive 2008/98/EC), Packaging Directive (Directive 94/62/EC), Landfill Directive (Directive 1999/31/EC), Waste Incineration Directive (Directive 2000/76/EC) that has been amalgamated into the Industrial Emissions Directive (Directive 2010/75/EU), Renewable Energy Directive (Directive (EU) 2018/2001), Commission Regulation (EU) No 1357/2014, Directive (EU) 2018/850, Directive (EU) 2018/851, and Directive (EU) 2018/852 (European Commission, 1994, 1999, 2008, 2010, 2014, 2018a, 2018b, 2018c, 2018d).

In the Waste Framework Directive and its modification EU shows properties of waste which render it hazardous, indicates the waste hierarchy (prevention, preparing for re-use, recycling, other recovery, e.g. energy recovery, landfill), introduces the End of Waste (EoW) criteria that specify when certain waste ceases to be waste and becomes a product, or a secondary raw material, and fixes aims in recycling of municipal waste for the next years. Directive 94/62/EC amended by Directive (EU) 2018/852 imposes the minimum aim of wood packaging recycling of 25% and 30%, within 2025 and 2030 respectively. Directive (EU) 2018/850 amending Directive 1999/31/EC on the landfill of waste stated that no more than 10% of all municipal waste should be landfilled by 2035. However, there is no Directive or Regulation that addresses WW management in detail. Consequently, we present an analysis of the main legislation and objectives related to WW management in European countries.

In 2002 Waste Wood Ordinance (AltholzV, 2002) was introduced in Germany. It governs the recycling, harnessing of energy, and proper disposal of waste wood, with a key focus on categorizing it into distinct waste wood classes I-IV and their corresponding utilization. German law fixes also limit values to render a waste idoneal to recycle in timber. It is the first law in Europe to categorize WW.

RecyclingholzV is the Austrian law governing wood waste recycling. It establishes pollutant limit values for WW used in the timber industry, particularly for products made entirely from recycled wood (100%). It introduces an innovative recycling factor, representing the percentage of recycled wood in timber. As a result, the limit values can be adjusted by dividing them by the recycling factor, depending on the proportion of recycled wood in the timber product. Additionally, this Austrian law outlines End-of-Waste criteria for waste wood based on pollutant content (RecyclingholzV, 2012).

European Panel Federation (EPF) sets forth limit values for contaminants that may be present in recycled wood. EPF draws inspiration from the CEN report CR 13387, titled “Child use and care articles – General and common safety guidelines” which establishes limit values for items that come into contact with children's mouths. The determination of limits for Fluorine (F), Chlorine (Cl), Pentachlorophenol (PCP), and Creosote is based on EPF's environmental evaluations (European Panel Federation, 2018a, 2018b).

In France, there is no specific legislation governing the quality of WW. However, a notable example of Extended Producer Responsibility (EPR) is evident in the wood furniture market, aimed at promoting reuse and recycling. In France, producers are required to either organize or finance waste management. Typically, this responsibility falls on collective organizations known as Producer Responsibility Organizations (PROs) or “éco-organismes”. PROs manifest in two distinct formats: organizational programs that amass fees from producers and utilize these funds to engage waste management operators, and financial initiatives which employ producer-collected fees to bolster municipalities responsible for waste management (Vis et al., 2016). In France, the usual classification shows 3 classes: A (clean products, without additives), B (lightly admixed products), and C (heavily admixed products) (Besserer et al., 2021).

In addition to the measures mentioned, there are other policies available in Europe, such as landfill taxes, bans on landfilling, incineration taxes, pay-as-you-throw systems (PAYT), and separate collection systems. These measures vary from state to state within the EU, where we can find some states leading the way and others that do not even have these measures in place. For examples, landfill taxes are currently applied in 22 EU Member States. The EU average is approximately 42.5 €/tonne of waste landfilled, with significant variation between countries, from less than 20 (e.g., Italy) to over 100 €/tonne (e.g., Belgium). Also, the other measures vary significantly within the European countries (EEA, 2023b).

In Italy, there are no specific legal limits imposed on contaminants in WW. While there is no outright ban on landfilling WW, combustible waste with a calorific value greater than 13 MJ/kg is prohibited from being landfilled (Cocchi et al., 2019). Landfill and incineration taxes in Italy are among the lowest in Europe (EEA, 2023b). Additionally, Italy employs a basic PAYT system based on the Tari tax, which is determined by factors such as the surface area of the housing, location, and the number of occupants, rather than being directly tied to the amount of waste generated (EEA, 2023a). WW is typically collected separately through waste collection centers, and many municipalities offer on-call collection services for bulky waste. However, it is worth noting that the level of service for WW collection may not be on par with the collection systems for glass, paper, and plastic (EEA, 2023a). For a more in-depth examination of these points, we recommend referring to the document from the European Environment Agency that pertains to Italy (EEA, 2023a).

Now, let's delve into a case study analyzing two waste companies in Umbria. In 2021, Gesenu and Biondi handled 5.416 tons and 3.522 tons of WW, respectively, excluding 200201 EWCc WW due to its classification as biodegradable waste. Table 2 presents pollutant analysis data provided by these companies for the mixed WW, encompassing all EWCc waste categories. We will compare these values with the limit values stipulated in Austrian and German laws, along with the EPF standard. Table 3 details the quantities of different EWCc waste categories within the considered companies.

Table 2. Comparison between the limit values set by German and Austrian laws, the proposals from the EPF, and the pollutant content in mixed WW after mechanical treatment

Parameters	***WW from Gesenu mg/kg***	***WW from Biondi mg/kg***	***EPF***	***Austria***	***Germany***
Chlorine (Cl)	648.5 ± 344.3	-[3]	1000	250	600
Fluorine (F)	<50	-	100	15	100
Arsenic (As)	<1	-	25	1.2	2
Cadmium (Cd)	<1	0.6 ± 0.4	50	0.8	2
Chromium (Cr)	2.2 ± 1.2	5.3 ± 2.3	25	10	30
Copper (Cu)	7.2 ± 6.5	33.9 ± 18.8	40	-	20
Mercury (Hg)	<1	n.a.	25	0.05	0.4
Lead (Pb)	10.3 ± 9.6	4.8 ± 0.8	90	10	30
Zinc (Zn)	48.5 ± 34.1	58.3 ± 16.9	-	140	-
PAHs[1]	-	-	-	-	-
Benzo(a)pyrene[2]	<5	-	0.5	2	-
Pentachlorophenol	-	-	5	-	3
Polychlorinated biphenyls	-	-	-	-	5

[1]PAHs (EPA) = Sum of 16 PAHs frequently monitored according to the recommendations of United States Environmental Protection Agency (EPA); [2]Benzo(a)pyrene (EPA) considered as a marker for the other PAHs according to EPA 3550C 2007 and EPA 8270E 2018; [3]Not determined

Table 3. Amount of WW per EWCc in the considered companies

EWCc	*Gesenu (tonnes)*	*Biondi (tonnes)*
03 01 05	0	298
03 01 01	0	7
15 01 03	368	2.254
17 02 01	21	925
19 12 07	299	17
20 01 38	4.728	21
Total	5.416	3.522

In each company, all of the EWCc materials were shredded and mixed in the on-site mechanical treatment plant, resulting in homogeneous wood waste labeled with the EWC code 191207. This processed waste was then sent for material recycling.

The first issue identified through the analysis is the varying legal contexts within the EU. As shown in Table 1, the two WW from these companies are used for recycling in Italy, particularly in particleboard production. However, this may not be feasible in other countries like Germany and Austria (it is different if consider a minor percentage of WW in recycling, see (RecyclingholzV, 2012) for details). Nonetheless, the samples generally comply with EPF standards. The primary concern here is the absence of a common EU law governing WW recycling. Notably, German law leans more toward energy recovery from WW. In Germany, approximately 70% of WW is incinerated for energy production, compared to nearly 17% in Italy. Conversely, when it comes to recycling, the situation is reversed, with Italy at 83% and Germany at 30% (Eurostat, 2023). It is mainly caused by three reasons: stringent recycling regulation in Germany, higher subsidies for renewable energy from WW in Germany compared to Italy (EEA, 2023b), and a shortage of wood material for the panel industry in Italy (Vis et al., 2016).

Another issue concerns the mixing of WW into a single EWCc. Maintaining separate streams of WW can enhance categorization into different qualities and improve material recycling and energy recovery. Faraca et al. (2019) conducted an analysis of various WW types, demonstrating the significance of the WW source in quality assessment. Therefore, maintaining distinct WW streams based on different EWCc categories could be the next step in WW management. This approach could lead to the attainment of higher quality standards, and further research could explore various recycling options beyond particleboard production, providing more choices for companies and municipalities. While particleboard production is likely to remain a reliable method for WW recycling, ongoing research is necessary to optimize diverse recycling options, taking into account variables such as local market context, new technologies (both in recycling and decontamination), scaling-up, sorting techniques (Hasan et al., 2011), distance from recycling plants, and more.

The absence of an EPR scheme for WW management across the EU is another policy issue. The French case demonstrates an improvement in recycling wood furniture (Vis et al., 2016), and this could be the first step to develop a common system in the EU.

Austria is the only state with EoW criteria related to WW (Vis et al., 2016). EoW criteria have the potential to prevent the unnecessary continuation of waste status, facilitating the trade and utilization of wood from WW in products. Therefore, a common set of EoW criteria in the EU is desirable to promote the use of WW in the market with uniform regulations. However, the introduction of EoW criteria should be approached cautiously, as it involves the loss of waste status and the subsequent inapplicability of the waste hierarchy.

Finally, WW management policy should establish a common European law for WW, encompassing pollutant limit values for recycling and energy recovery, mandatory EPR for WW, EoW criteria for WW, compulsory separate WW collection to enhance existing measures, and the enhancement of WW quality by avoiding the mixing of different EWCc categories. Each of these measures should be carefully studied to make the system dynamic and suitable for the diverse environmental, economic, and social contexts of the European Union.

4. Conclusion

This paper thoroughly examines the policy framework within the European Union, specifically focusing on wood waste recovery, and identifies several critical issues that need to be addressed to enhance this process. The findings highlight the importance of creating a robust decision-making tool for wood waste management, which will be further analyzed in forthcoming studies.

To achieve the objectives outlined in this paper, future research must delve into existing literature to identify and clarify the technical challenges associated with different types of wood waste. This will involve a comprehensive review of the current state of wood waste management practices, technological limitations, and potential innovations. By understanding these challenges, researchers can pinpoint the barriers that hinder effective wood waste recovery and identify opportunities to overcome them.

Moreover, the development of a decision-making tool for wood waste management will necessitate a multidisciplinary approach, integrating insights from environmental science, engineering, economics, and policy analysis. This tool aims to provide stakeholders with a reliable and systematic method to assess and implement wood waste recovery strategies. It will consider various factors such as economic feasibility, environmental impact, and regulatory compliance.

In addition to technical and policy-related challenges, the research should also explore the socio-economic dimensions of wood waste recovery. This includes assessing the potential for job creation, community engagement, and the development of new markets for recovered wood materials. By fostering a circular economy approach, the decision-making tool can contribute to sustainable development goals, reducing the environmental footprint and promoting resource efficiency.

Ultimately, these comprehensive analyses and the development of a reliable decision-making tool will provide a solid foundation for improving wood waste management practices across the European Union. This will not only enhance resource recovery but also support the EU's broader environmental and sustainability targets, paving the way for a more circular and sustainable economy.

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THE ROLE OF AI IN SUSTAINABLE OPERATIONS AND MAINTENANCE BY REDUCING WASTE*

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Abstract

The research aims to examine how consumable type waste in the power production industry can be reduced. The paper describes a theoretical model that extends knowledge by developing and applying a practical model, thereby significantly impacting the environment by reducing the number of consumable maintenance elements used during the asset life cycle.
The practical implication in this case study is a potential annual reduction of 17.280 non-recyclable filter elements per power station equipped with the current large gas turbine generating units, thereby reducing waste material (used consumables) by 67% over an approximate 3-year cycle, consequentially reducing carbon emissions of shipping 16 freight containers. In addition, avoiding emissions in the upstream logistics, e.g., the production phase of the consumables.
The research study investigated the potential of artificial intelligence (AI) to enhance decision-making. Furthermore, conducts a dual-focused inquiry, exploring AI's ability to analyse accurately and forecast Operation and Maintenance data, thus aiding business decisions by reducing uncertainty.
The study reveals that AI can boost statistically based decision-making if implemented correctly by a motivated management team. The research extends the application of resource-based theory and the knowledge of predictive planning systems.

Keywords: artificial intelligence, consumables, environmental impact, maintenance

1. Introduction

Consumable waste is generally considered packaging (European Commission, 2022), office paper, and food. However, in the power industry, equipment consisting of parts is classified as either refurbish-able spare parts or consumable spare parts (Zhang et al., 2021). Typically, machines used in the power generation and energy field are manufactured by

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Original Equipment Manufacturers (OEM) and supplied with operational and maintenance manuals specifying standard preventative maintenance tasks and their frequency. Duties may vary from lubrication to routine parts replacement, e.g., air filter elements.

The replacement frequency is generally conservative to prevent deterioration or damage to the equipment. The OEM manuals typically recommend the inspection and replacement frequency subject to the environmental conditions where the equipment is installed. For example, dusty conditions and high temperatures require more frequent maintenance. Herein lies the Operations and Maintenance managers' decision regarding following the manual or the actual performance data of the equipment to replace consumable parts. Even with the history available from the telemetry, there is low confidence that the trend predicts the future performance of the equipment, predicting the likely remaining useful life of the consumable part (e.g., air filters).

Traditionally the approach would be to replace the consumables as per the OEM manual. However, some consumables are large volumes of parts, e.g., Gas turbine inlet air filters which can potentially consist of thousands of individual elements, representing high costs (and emissions) in supply chain logistics, import duties, and waste disposal services of the spent filter elements. The UK government reported a consistent industrial sector waste volume of approximately 14 million tonnes in the past decade (https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs).

The objective of this study is to provide an evaluation of using artificial intelligence (AI) and machine learning (ML) made in operation and maintenance to support decision-making. In particular, the decision to plan the replacement of high-volume long lead time consumable parts, thereby reducing the environmental impact. The initiative is that the utilisation of the components is increased and further optimised to exhaust the part without compromising the equipment.

The research work is divided into three sections.

- Evaluate the capability of current AI technology: a literature review indicated a few fundamental papers regarding long-term planning and AI model-based learning in Proceedings of AI and Maintenance 4.0 (the evolution of maintenance philosophy) as the next evolution step in industrial maintenance development (Poor et al., 2019).
- Applying the available AI technology to accurate case data: data from a selected case (power plant) were used as an example to provide equipment telemetry in comma-separated value (CSV) format. The data was then separated into a training data set, and a test data set, and eventually, an AI model was applied to learn the behaviour of the individual telemetry data variables.
- Analysis of results of the experimental AI model application to data: the AI model utilised neural network and linear regression methods to learn and predict the behaviour of the data points. The predicted values were applied to the test data set from the original split data set to test the accuracy. After fine-tuning the parameters of the AI model, a repeatable result could be created with high accuracy.
- The hypothesis states that waste reduction is possible if consumables are more efficiently used. However, environmental uncertainty prevents optimisation because of the size and volume of the consumable parts order batches, lead times and logistics involved, reducing the margin for error in case of an incorrect prediction/decision. If AI could prove high accuracy in the range of 97%, the uncertainty barrier could be substantially reduced or overcome. Therein lies the benefit of historical data on power plants already in service at the given geographic location and environmental operating conditions.

4. Materials and methods

The methodology selected was a quantitative approach, focusing on the capability of AI to predict the behaviour of consumable elements in a given environment, reflected in the data set as an objective. The positivism philosophy focuses on finding answers to whether AI can provide confidence in decision-making. Quantitative data was derived from a modern combined cycle gas-fired gas turbine power plant case. The data modelling was adopted from a similar study by Charumilind et al. (2020) to evaluate whether the model fits for purpose. The model's validity is proven through reliability in the repeatability of the experiment and being 'fit for purpose'. The study is built on a similar method used in a previous study to develop a maintenance model (Del Carmen et al., 2016). Data were derived by exporting data points from a telemetry system which records data from instrumentation at minute intervals with no human intervention in the data reaching 13.118 rows by 9 columns.

Data processing was achieved by utilising the Google Colab TensorFlow platform, which uses Graphic Processor Units (GPU) to perform processor-intensive neural network processes. Data were randomly split into a training set and training and a test data set in a ratio of 80/20. Followed by calling the *'Seaborn.pairplot'* function to create an axis grid and drop any missing values from the dataset via a Boolean function (Poor et al., 2019). Feature engineering ensured accuracy and sped up data processing (Filus and Domańska, 2023) by selecting data into features and labels.

After normalising the data (transforming the data in columns to a standard scale without distorting the differences between values), the experiment was run using a linear regression model, proven to be successful in predicting the future (Khan and Ahmed, 2020). The linear regression method predicts a selected variable based on the other variables in the data set. In this case, the project predicted the differential pressure (performance) of one of the filter element stages based on the upstream and downstream filter element differential pressure (performance).

The accumulated evidence highlighted inconsistencies in the linearity of the data set. It is known that AI neural networks can learn and predict complex learning of non-linear data relationships (Ghimire et al., 2022). The study expanded the AI model to include a neural network to more accurately process the 3D data elements in multiple layers.

5. Results and discussion

This paper presents the findings of a quantitative study in a potential method applied to reduce the impact of consumable parts on the environment. The study aims to optimise the replacement of consumables, specifically the gas turbine filtration system elements, as an example of the potential benefit of intelligent decision support system capability of AI data analysis and prediction. Consumable reduction subsequently has a compound reduction in carbon emissions in upstream shipping and manufacturing processes and downstream waste transport, handling and disposal. Various factors affect the decision to replace consumable parts. Factors may include the assumption that gas turbines operate adiabatically and isotropic; the efficient steady-state energy flow equation is to be ensured by the design parameter for the range of operation of the filter elements, measured in differential pressure (www.ijmsssr.org). The linear regression model prediction of the differential pressure of one of the 3 stages against a downstream filter stage, plotted against actual data, achieved 97.2% accuracy.

Fitment of the model optimised at 96 epochs at the lowest losses processing the 13,000 rows of data 96 times in 1 minute and 22 seconds. Further refining the linear regression model, a Deep Neural Network (DNN) model was developed to add non-linear layers (not directly linked to the input and output) to the AI model. The model was trained using Keras '*model. Fit'* function set to 100 epochs with a 20% data validation split, resulting in improved accuracy.

5.1. Practical contribution

Figure 1 compares a conservative and typical suggested filter replacement frequency for a single 400MW gas turbine. The AI-assisted yellow bars can likely be further optimised by only replacing the required stage (of the 3 stages of filtration in series) by using the research model to predict the behaviour of the filter stages concerning each other. Further data analysis indicates that in Fig. 1, there is an expected 65% reduction in filter elements. The practical impact in the power plant analysed is a reduction of 13 shipments totaling 104 sea containers between continents. This would result in the prevention of the waste disposal of 28.080 filter elements.

Multiplying these findings by 8 gas turbines per power plant, the impact becomes significant by avoiding manufacturing 224.640 filter elements, 104 shipments and the contents of 832 containers (62.350 m^3) of waste in landfills over the 20 years per power plant, expected to run for 30 years. The period of 20 years was selected as an indication to already commissioned power plants of the potential savings and environmental impact.

5.2. Academic contribution

The study is based on resource-based theory (RBT), extending the application of predictive planning technologies to optimise resources (Ahmad and Wu, 2022). There are various ways to improve resource consumption, principally by making the most of the resource by more efficient utilisation. In addition, providing a sustainable competitive advantage through increasing the value of the resource.

The study extends the application of AI in the planning and utilisation of consumables in the power industry operation and maintenance (PIOM) sector by applying the AI DNN algorithm to the engine telemetry of gas turbine consumable elements. Thereby reducing uncertainty in consumable consumption without increased risk to the equipment warranties.

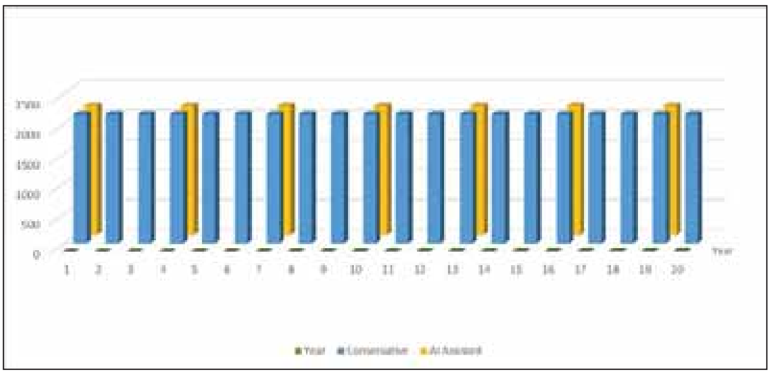

Fig. 1. Comparison over a twenty-year life cycle, the number of filters used per gas turbine comparing the standard protocol in blue compared to the potential protocol in yellow which may be further improved

Literature signals that businesses in macroeconomics are competitive and seeking to take advantage of AI technologies, despite the barriers preventing implementation. Nevertheless, when the technical engineering skills and knowledge of processes in operation and maintenance are combined with the capability of AI, an undeniable opportunity becomes available to reduce costs, but foremost become more efficient in the use of company resources, therefore, environmental resources. With approximately 62.500 power plants in operation worldwide (Raj et al., 2022), the results could potentially significantly impact the carbon footprint by optimising the consumption of consumable parts.

The study's limitations are related to the case data being of one geologically sensitive. Individual power plant site locations are exposed to unique environmental and operational conditions. Less dusty conditions, for example, lead to longer-lasting air filter performance. In addition, the skills and experience of the engineers and AI programmers developing the AI models at sites are critical to the accuracy and repeatability of the AI model. However, there are mitigating actions to apply in the implementation stage of AI for further research specific to the energy sector.

6. Conclusion

National resource efficiency is fundamental to improving eco-efficiency by facilitating financial deepening and diversifying the economy through technological progress. Therefore, a unilateral causality originates from implementing resource-based theory, improving consumption rates.

Literature signals that businesses in macroeconomics are competitive and seeking to take advantage of AI technologies, despite the barriers preventing implementation. Nevertheless, when the technical engineering skills and knowledge of processes in operation and maintenance are combined with the capability of AI, an undeniable opportunity becomes available to reduce costs, but foremost become more efficient in using company resources, therefore, environmental resources.

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