Waste Cooking Oil: State of Art on a Circular Economy View

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Abstract

Never before has there been a need for collaborative interactions between industry, the scientific community, policy makers and citizens. This has become crucial for the development of shared political choices, the protection of human heritage and the environment, to guarantee a decent future for generations to come. The aim of this work is to provide a general overview of EU policies/regulations, market impact and valorisations through a circular economy model aiming to create new products by reusing used cooking oil (WCO), avoiding its discharge in the environment.

1. Introduction

Scientific and industrial progress in the last century has indirectly led to the creation of social, environmental and human health issues. As a consequence, in the last decades, an increasing awareness of the consequences of human activities on Earth had led to the development of new strategies aiming to limit the depletion of resources and the environmental impact of industrial activities.
Terms such as "sustainability", “circular economy” and “eco-design” refer to a new way of thinking aiming to reduce the impact of human activities by different strategies among which the vaporization of end-of-life products as secondary materials represents one of the most appealing strategies, generating economical value and reducing environmental impact of household and industrial activities.
The 2030 Agenda for Sustainable Development is the United Nations (ONU) program of action promoting economic growth, social inclusion and protection of the Environment endorsed by the governments of the 193 member countries of the ONU thus placing a defined plan aimed at sustainability in environmental, social, and economic terms. This program incorporating 17 Sustainable Development Goals - Sustainable Development Goals, SDGs - declined into a total of 169 targets, led each country to have its own national strategy actively involving public and private actors. The article proposed here is divided into a first part of current analysis of the hospitality and tourism sector in terms of circular economy and a second part of analysis and academic research regarding the use of waste cooking oil (WCO) in the creation of new products called "second life products".

2. Circular Economy in the hospitality and tourism sector

The hospitality and tourism sector stands as one of the world's largest industries, contributing significantly to economic prosperity. However, alongside its diverse economic advantages, this industry is acknowledged for generating notable negative impacts on the environment, society, and culture. Despite the acknowledgment of sustainability's increasing significance in tourism and hospitality (Boley, 2011), there persists a challenge in addressing the intricate issue of environmental sustainability in this specific sector (Jones and Wynn, 2018).

A recent literature review on the topic reveals that the timeline of research activities on the circular economy in the hospitality sector began to emerge around 2018, with a few exceptions, while farm-to-fork and sustainability perspectives gained attention between 2017 and 2018. Waste management has consistently been a common thread throughout the articles, spanning from 2013 to 2021 (Bux and Amicarelli, 2023).

This challenge remains an ongoing concern for academics, policy makers, and industry professionals in the field of hospitality and tourism sector. Despite the extensive application of the circular economy concept in sectors such as agriculture, manufacturing, and construction, its incorporation into tourism has remained restricted (Ming, 2006; Pattanaro and Gente, 2017).

In the literature dealing with the exploration or application of the circular economy concept into tourism, many papers look at farm to fork and sustainable waste management strategies in the hospitality industry (Dolnicar et al., 2020; De Grosbois and Fennell, 2022; Kim and Hall, 2019), while some others have delved into specific tourist destinations and activities. For instance, Zhang and Dong in 2015 addressed challenges in developing a circular economy model for the Mount Emei Scenic Area in Sichuan Province, proposing solutions such as increased government involvement, green procurement practices, waste management, energy-saving initiatives, and eco-friendly tour routes. Scheepens et al. in 2016 conducted a case study on a business model for sustainable water recreation in Friesland, The Netherlands, exploring ways to transition to a sustainable business through benchmarking and stakeholder analysis. Despite environmental benefits, the lack of customer appreciation hindered strong support, illustrating challenges in market competition.

Regarding the hospitality industry, the academic literature has shown limited attention to the circular economy. Van Rheede in 2012 suggested that applying circular economy principles in hospitality and tourism can accelerate business growth and create a more sustainable experience for stakeholders. While some studies estimated the environmental and financial benefits of waste recycling in the hotel industry, a specific academic focus on the circular economy within hospitality is still emerging. Overall, water and waste management, together with energy consumption monitoring are increasingly recognized as vital aspects of a sustainability strategy in the tourism and hospitality sector, necessitating robust systems for data capture, processing, analysis, and reporting (Jones and Wynn, 2018).

In the realm of restaurants, sustainability and circular practices have been the focus of various research areas (Bux and Amicarelli, 2023). Authors have examined farm-to-fork strategies, emphasizing local food consumption, short food supply chains, and circular economy strategies such as nutrients recycling, food composting, biodiesel production, and energy recovery (Scozzafava et al., 2017; Paciarotti and Torregiani, 2018; Carmona-Cabello et al., 2018, 2019; Velazquez Abad et al., 2015). Food waste management practices have evolved toward circular economy strategies, focusing on economic and environmental savings, waste minimization, cost reduction, and creating value-added products (Gruia et al., 2021; Camilleri, 2021). The latter involves reusing and recycling food raw materials, as exemplified by sustainable menu creation, increased local procurement, and sharing economy platforms for surplus food recycling. Sustainable strategies also extend to alternative consumer choice architectures and local food approaches. Menus play a vital role in informing customers about the environmental and societal implications of their choices. Carbon footprints and descriptive menus are considered instrumental in promoting climate-friendly eating habits (Bacon and Krpan, 2018).

3. The Waste Cooking Oil case

Spent vegetable oil referred to as WCO (Waste Cooking Oil), derived primarily from the use of vegetable oils in the hospitality industry, poses several disposal issues both from an environmental and economic point of view.

Globally, vegetable oil production in 2021/2022 was around 209 million tons (Global vegetable oil production since 2000), where in Europe alone the consumption of vegetable oils was 24 million in 2022 (vegetable oil consumed in the European Union), indirectly generating a significant amount of WCO to be disposed of as a waste.

Vegetable and frying oils become waste since during usage it undergoes a process of oxidation, becoming no longer suitable for human nutrition due to the loss of its main chemical/physical characteristics. In Italy, D.lgs 152/2006 regulates means for proper recovery and disposal of WCO and identified it with a EWC code (European Waste Catalogue), derived from a harmonized European list (Decision 2000/532/EC) and subject to continuous revision. The CER code allows to identify by means of a six-digit code, the different types of waste and to the specific procedures to be followed for its proper storage, recovery or disposal (Decision 2000/532/EC, Annex D D. Lgs. 3 April 2006, n. 152).

It is composed of the first two digits that refer to the category or activity that generates the waste (industrial sector from which the substance originates), the middle pair of digits that refers to the production process that generates that waste, and the final pair of digits that specifically identifies the waste (substances actually contained within the waste).Therefore, waste vegetable oil (WCO), classified with a specific EWC Code (EWC 200125, edible oil and fat waste), even if categorized as not hazardous to human health, becomes potentially harmful to ecosystems if disposed incorrectly, obliging the producer of the waste to follow defined procedures, and preventing the waste from being improperly dispersed into the environment.

In Italy, for example, any operator involved in the collection, transportation, storage, recovery and regeneration of exhausted vegetable/animal oils and fats is obliged to register to the CONOE consortium *(*National Consortium for the Collection and Treatment of Exhausted Vegetable and Animal Oils and Fats established under Legislative Decree 22/97;amended by Legislative Decree 152/06 Art. 233 et seq.mm.ii), responsible for organizing, controlling and monitoring the exhausted vegetable and animal oils and fats supply chain for environmental purposes.

The reuse of WCO therefore poses new challenges, both from the perspective of environmental sustainability by reducing the environmental impact that this waste has throughout the disposal chain, and in economic terms, by reducing disposal costs (Cárdenas et al., 2021).

Therefore, scientists are looking to implement different methodologies to convert WCO into a useful resource as a secondary raw material to produce energy or high value-added products. Indeed, the recovery of WCO poses a challenge, and the possibility of using it as a secondary material is an important solution. In fact, WCO can be used as a new resource to produce a wide range of bio-based products that are not dependent on the fossil supply chain bringing further benefit in terms of both economics and sustainability.

In general, WCO is mainly composed of 95% triglycerides with aliphatic chains ranging from 16 to 18 carbon atoms (Foo et al., 2022) derived from palm, soybean, canola, sunflower, peanut, cottonseed, coconut, olive, and corn. At present, the main use of this waste is in the bio-fuel sector, mainly biodiesel, as a substitute for virgin feedstocks.

In fact, the use of virgin oils poses an issue of sustainability and competition with the food supply chain leading the scientific community and the industrial sector to develop and implement in recent decades new technologies for the use of WCO as the main source in biodiesel production.
Leaving aside its main use as a renewable source for biodiesel production, WCO can be chemically modified and used as an additive for plastic materials (Foo et al., 2022), as a binder for the formulation of new compounds for the construction market like Bio-Asphalt (Azahar et al, 2016; Wang et all, 2017), Cement (Liu et al., 2020; Li et al, 2016) or as a source of polyols for the formulation of polyurethanes in construction, opening up new challenges in science directed toward the use of used cooking oil as a secondary life raw material.
In this paper, the different methods of recovery and recycling of WCO reported in the literature in the last ten years, to produce innovative products such as plasticizers for the plastics market, polyurethanes, asphalt rejuvenator, and biosurfactant will be explored.

4. Properties and chemical composition of waste cooking oil (WCO)

WCO consists of mainly triglycerides and by-products such as free fatty acids, glycerol, monoglycerides, diglycerides, terpenes, is produced by subjecting vegetable oil to a cooking process at high temperatures, usually between 150°C and 200°C (Foo et al., 2022). During this process, the vegetable oil undergoes degradation leading to a chemical and physical change in the initial properties of the oil. The chemical degradation processes (Carmona-Cabello, M. et al., 2018) are, for example, oxidative processes (formation of alkanes, alkenes, symmetric ketones and dimeric compounds), hydrolysis (increase in polar compounds such as free fatty acids, glycerol), polymerization (formation of triacylglycerides, dimers, oligomers), leading to the change of physical properties such as, colour, viscosity, density, and chemical change in terms of chemical composition of fatty acids, acidity value. In addition, the cooking process and the resulting oxidative mechanisms give rise to by-products (aromatic and heterocyclic) with toxic properties, thus placing a ban on the use of such waste in the food supply chain. In addition, traces of the foods remain in the oil, further contaminate and alter the original composition of the vegetable oil.

4.1 Physical recycling of waste cooking oil

The pretreatment process of WCO is a crucial step in the reuse of this raw material as a new biobased primary source (Carmona-Cabello, M. et al., 2019). Numerous articles exist in the literature regarding pretreatment methodologies for purifying WCO from the various contaminants produced in the cooking process. These processes, being complementary, should be analysed and implemented based also on the intended use of the raw material in question. For example, for the fuel compartment (biodiesel from a non-fossil source), the second-life material must have defined parameters of acidity, moisture, and oxidative value in order to be used, or if used as a plastic additive, various standards related to the volatile components present in the spent oil must be met. It is possible to divide the pretreatment process into three main categories:
- Separation by solubility: water extraction allows to separate polar compounds present in WCOs which are more soluble in water than in WCO.
- Separation by filtration: specific filters such as membranes, activated carbon, cellulose, silicates allow purification of the spent oil from solid residues. The choice of filter must take into consideration the type of sediment and impurity to be removed based on its physical characteristics (particle size, density, viscosity) and the cost of the purification process.
- Separation by distillation: by distillation at reduced pressure the spent oil can be purified from volatile compounds.

5. Waste cooking oil as oleochemical feedstock into valuable products

Nowadays, numerous applications even in industry see the use of WCO for the energy sector, as for example to produce Syngas (Carmona-Cabello et al., 2019; Naik et all, 2010) or for the fuel sector as a new source of biofuels. With increasing knowledge about the average chemical composition of WCOs, the academia first and then industry are exploring the use of WCOs for new bio-based applications by expanding the possible range of biobased products from WCOs.

5.1 New bio compound from WCO for Polyurethane synthesis

Polyurethanes (PUs) are an important class of polymers obtained mainly through a polymeric reaction between di-isocyanates and diols. Due to the broad chemical and physical characteristics of these polymers, it is possible to have different families of polymer products such as flexible foams, rigid foams or nonporous materials covering numerous application areas ranging from the automotive sector to the construction industry.

The global market volume of polyurethanes stood at nearly 26 million tons in 2022 with a volumetric estimate of 31 million in 2030 (Mannu et al., 2020; Market volume of polyurethane worldwide from 2015 to 2022, with a forecast for 2023 to 2030) positioning itself as a major player in the polymer market.

Currently, PU materials are prepared from virgin naphtha, however, scientific research is geared towards replacement with renewable raw materials. In fact, sustainable development occupies a valuable place due to dwindling oil resources, greenhouse effect and new environmental protection regulations. Therefore, many studies have pointed to the possibility of replacing petroleum-based raw materials with agricultural resources such as lignin, cellulose, starch, and vegetable oils (VO). The latter materials are known to be more useful because of their biodegradability, low price and availability in various forms and low toxicity. In this context, many efforts have been made in recent decades to make polyols from WCO to produce new high value-added products such as polyesteramides, polyetheramides, epoxy resins, and various PU materials (Fareeha Marriama et al, 2023; Orjuela et al, 2020).

As reported by Asare (Asare et all, 2022), modification of WCO from local commercial activity by epoxidation and ring-opening reactions, allowed to obtain a rigid polyurethane foam with chemical and physical properties alike common polyurethane materials used in building and construction.

Another use of WCO is reported by Lubis (Lubis et all, 2021), where sugar palm (Arenga pinnata) fibre reinforced by polyurethane foam was prepared compounding WCO, polyols and toluene di-isocyanate producing a cross-link improving the interfacial adhesion between the fibre and the matrix. Additionally, WCO has been tested as a precursor for super-hydrophobic coating applications through a process of amidation of WCO followed by subsequent functionalization with isocianates and dimer fatty acid (Paraskar et all, 2020) or with isocianates and amino-terminatedpolydimethylsiloxane (ATP) (Cheng et all, 2019).

5.2 Additives for Polymers

With the introduction of new regulations that are increasingly restrictive in the use of components classified as toxic, research is opening new horizons for the use of new bio-based components as additives in the plastics industry (Jia et al, 2018). The addition of additives as plasticizers plays a very important role in modifying the chemical and physical properties of polymers (Bocque et al, 2016). Plasticizers are low molecular weight organic molecules that are added as one of the additives to plastics to act as lubricant among the polymer chains. Plasticizers (Agus et al, 2017) have been extensively used with polymers for producing flexible plastics, for example in the production of Polyvinyl chloride (PVC), by lowering the glass transition temperature (Tg). PVC resins have been widely used in food packaging, medical devices, building materials but, without any additives, is very hard and brittle at room temperature (Rahman et al, 2004).

Industrially the additive mainly used, in the production of PVC, is dioctyl phthalate, a highly toxic component, subject to REACH restriction in Europe (Annex XVII) for the toy market, food packaging materials, medical instruments (Bider et al, 2020; Cheng et al, 2020). A negative aspect of this compounds is that they possess a high mobility and an easy diffusion to the surrounding media for example food, solvent and primarily which contain a high fat (Zygoura et al, 2007).

The recent approach, in line with the global demand to reduce more and more fossil-derived chemical compounds, therefore sees WCOs as a new non-toxic, biodegradable, and readily available additive for the plastics industry.

As reported by Liu et al. (Liu et al., 2020) acetylated-fatty acid methyl ester-trimellitic acid ester (AC-FAME-TAE), obtained by modification of WCO, may be used as additive in PVC production giving a product with chemical and physical performance in line with the common industrially used additive (phthalate), making it an excellent substitute in terms of product safety and environmental safety.

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