Green Chemicals from Used Cooking Oils: Trends, Challenges and Opportunities

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ABSTRACT

Food waste reduction is fundamental for sustainable development and pursuing this goal, recycling and the valorization of used cooking oil (UCO) can play a major contribution. Although it has been traditionally used for biofuels production, the oleochemical potential of UCOs is vast. UCOs can be used as feedstock for a large variety of value added green chemicals including plasticizers, binders, epoxides, surfactants, lubricants, polymers, biomaterials, and different building blocks. Thus, UCOs transformation into functional chemicals can bring long-term stability to the supply chain, avoiding the current dependence on commodity products. In this regard, this work describes some of the potential benefits of using UCOs as feedstock in oleochemical biorefineries. Also, some of the most recent investigations on the valorization of UCOs other than biofuel are presented. Finally, major challenges and future directions are discussed.

Keywords. Used cooking oil, biobased chemicals, value-added products, challenges

1. Introduction

Reduction of food loss and waste is paramount to fulfil the UN's Sustainable Development Goals, and crucial to curtail their associated economic, social and environmental life cycle impacts. Current estimations indicate that average per capita food waste generation in Europe ranges between 173 - 290 kg/person·yr [1]. Equally alarming numbers (in kg/person·yr) are observed in Australia (361), USA (278), Canada (123), India (51), China (44), and other countries [2]. Reported data also reveals that nearly 60% of food waste is generated as consumption and post-consumption residues (e.g. bones, cooking oils, peels, leftovers, etc.), and a large fraction is unavoidable or inedible [1]. In order to mitigate the impacts, different circular economy approaches have been proposed for the exploitation and valorization of food waste via transformation into a large variety of chemicals, materials and fuels through a biorefinery approach [3-6]. The potential valorization processes and the targeted products largely depend on the nature and composition of waste. Besides carbohydrates, starches, and proteins, a large fraction of typical food residues corresponds to fats and oils (i.e. up to 25% wt. on a dry basis, [4, 7]). Particularly, among the different food wastes, discarded used cooking oil (UCO) is a major source of lipids. While suitable processes are required to extract the lipid content from most food waste [7], lipids in UCOs are readily reachable. This explains the existing UCOs collection chains and the different processes for their valorization at an industrial scale [8-10].

UCOs are mainly generated in households and hospitality sectors (HORECA – Hotels, Restaurants, Casino-Cafe-Catering) [11, 12], and the current global production is estimated between 20 and 32% of total vegetable oil consumption (41 - 52 Mt/yr., [9, 13]). This broad range is a result of the different culinary customs and consumption trends in the different regions, which also play a major role in the nature, chemical composition, and content of impurities in the UCOs [8]. Because of unconscious behaviors, absence of regulations, or lack of law enforcement, most UCOs are generally disposed through sinks and syphons, or within the solid residues that are sent to landfills. In addition to ecosystems pollution and public health impacts, this mismanagement generates a variety of cascading problems including sewage clogs, wastewater overflow, costly damage to infrastructure, vectors and pests, nauseous odors, higher operating costs at central wastewater treatment plants, etc. In order to mitigate all these problems, a fraction of UCOs have been typically recovered and reused as oleochemical feedstock, mainly for the production of low added-value commodities such as biofuels (e.g. biodiesel, hydrogenated vegetable oil - HVO), soaps and animal feed. This has created a small but solid market of nearly 600 Million USD/yr., growing at an average annual rate of 4% [14], and with prices in the range from 620-865 USD/t during the last 12 months [15]. In spite of the growing trend, and because of the low added-value of current derivatives, UCOs market is highly vulnerable to the change of economic and political environment. This vulnerability could be reduced by diversifying the portfolio including high value-added byproducts, thus bringing long-term stability into the entire valorization chain. In this regard, this work describes most current research on the transformation of UCOs into high value added biobased products, the challenges for a successful industrial implementation, the associated benefits, and some future directions.

2. Potential benefits of UCOs as Oleochemical feedstock

The main raw materials of the oleochemical industry are vegetable oils and animal fats, with the former having a 99.9% share in volume, and the remaining small fraction corresponding to butter, fish oils, and fats from animal rendering [16]. Figure 1 presents the historical production of vegetable oils and the corresponding distribution regarding final use. As observed, 68% of current world production is used for food applications (i.e. cooking oils, food ingredients), and 23% in biofuels, mainly biodiesel (~1.1kg_{Oil}/1$kg_{Biodiesel}$). The remaining fraction (~9%) is destined for feed and other oleochemical uses including drop-in applications (e.g. additive for polymers, resins, asphalt, lubricants, greases, drying oils, rubber products, etc.) and as feedstock for different chemical derivatives. Taking into account the estimated global UCO generation (41 Mt, [9]), this amount can replace the virgin vegetable oil currently required as feedstock for the oleochemical industry, a part of which is used as a biodiesel feedstock. Hence, the exploitation of UCOs as chemical feedstock within a circular economy model would help to reduce the environmental and social impacts associated to both, the edible oil and the oleochemical industries.

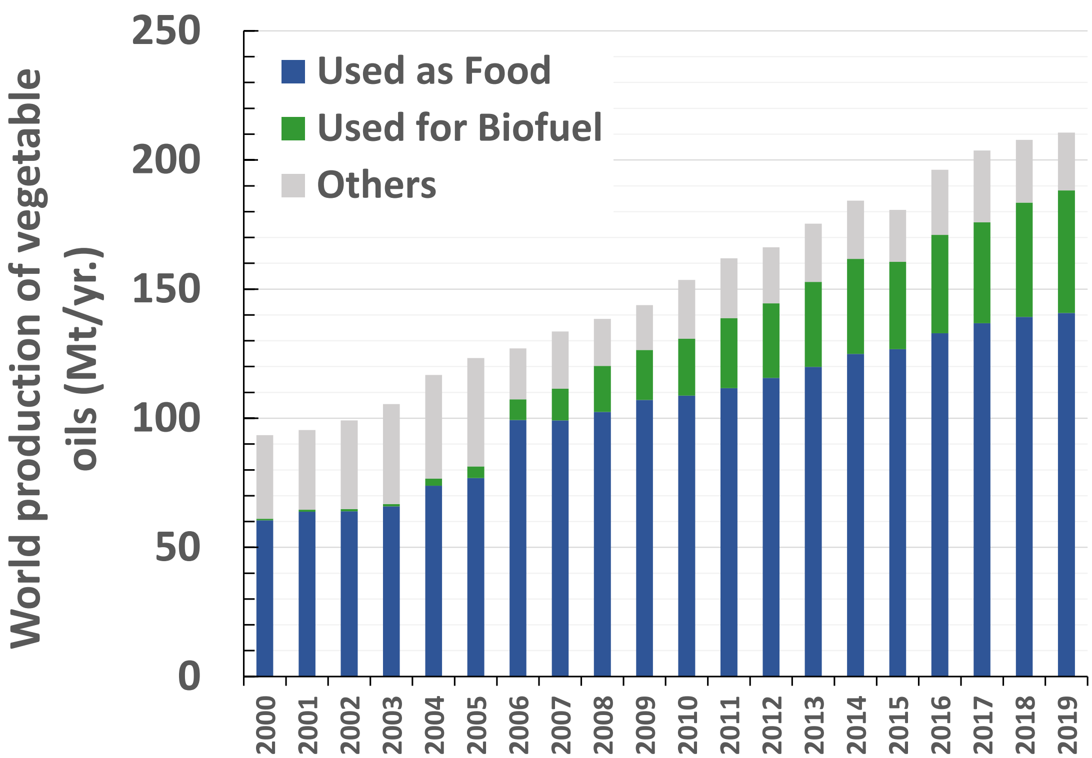

Figure 1. Historical world production of vegetable oils and share among final uses (Data from [16]).

Figure 2 schematically presents the different stages in which negative social and environmental lifecycle impacts could be mitigated by using UCOs as oleochemical feedstock [17-22]. This is based on a 100% efficiency in UCO collection and reuse, and considering the more conservative estimation of UCOs generation with respect to vegetable oil consumption (20%, [9]). Also, it is important to consider that for instance in the EU, only 45-50% of collectable UCO is recovered, with a best-case scenario of 70% [11, 23].

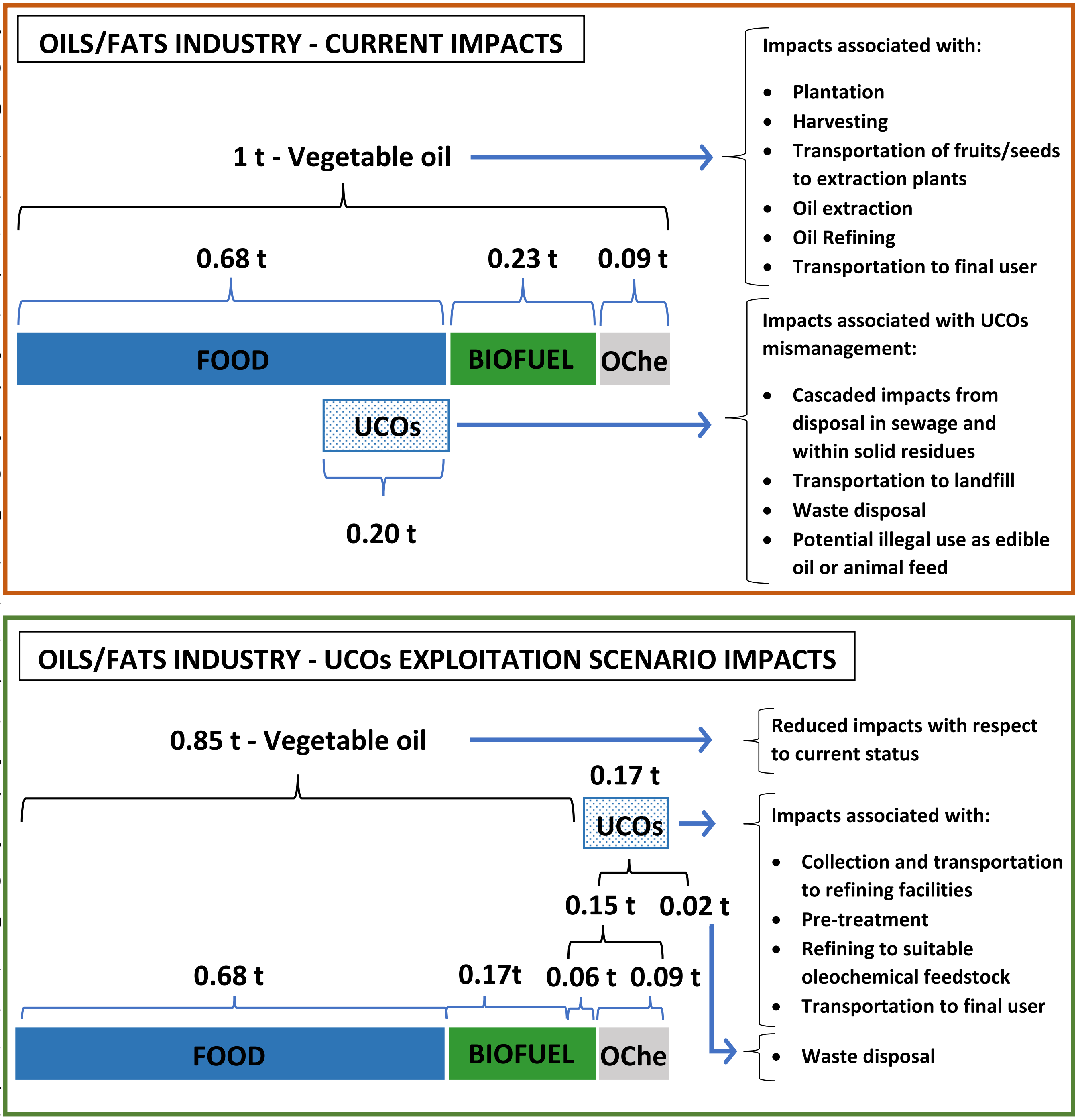

Figure 2. Potential impacts mitigation of employing a circular economy approach in the exploitation of UCOs as oleochemical (OChe) feedstock considering lifecycle stages (Cradle-to-gate.). Functional unit: 1 t vegetable oil. Assuming a 90% yield of refined UCO from the collected one.

3. High value added application for UCOs

The valorization of UCOs via transformation into suitable oleochemical products have captured the attention from academic and industrial researchers during the last two decades. Figure 3 presents the evolution of the scientific production (i.e. papers and patents) dealing with the exploitation of UCOs. While the studies on biodiesel are still predominant, there is an increasing trend to explore novel applications, mainly focused on value-added products. In addition to the availability of financial resources, most research have been conducted in countries where UCOs mismanagement can be a major problem, either because of their large population (e.g. China, India), or for the large per capita generation (e.g. USA, Indonesia, S. Korea). Most EU countries are grouped as “others”, and in this case, their large scientific productivity has been promoted by the public policies of the community [20].

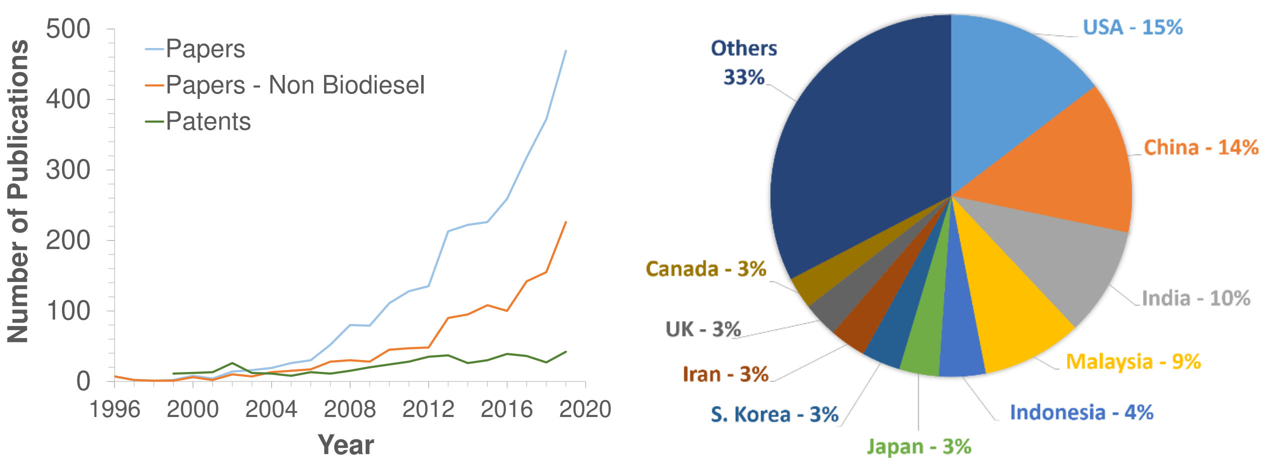

Figure 3. Number of publications and patents on the valorization of used cooking oil in last decades, and share by major contributing countries (March, 2020). Searching terms: TITLE-ABS-KEY ("Used cooking oil" OR "Waste cooking oil" OR "Yellow grease" OR "Brown grease" OR "Trap grease") (Source: [24-26]).

Recent reports indicate that biobased products can have a large market growth in the coming years, if similar policies and subventions to those implemented to the production of biofuels, are also implemented for green chemicals [27]. In this context, a variety of new processes and products have been developed for UCOs valorization, evolving from basic drop-in applications, to more complex thermochemical, chemical and biochemical transformations [28-31]. More recently, further exploration has enabled the development of value added products from the crude glycerol obtained as co-product from UCOs-based biodiesel processes [32, 33]. While this is not intended to be a comprehensive review of the available literature, Table 1 presents a summary of the most recent attempts for UCOs harnessing, including the production of plasticizers, binders, epoxides, surfactants, lubricants, polymers, biomaterials, building blocks etc.

Table 1. Most current attempts on the production of biobased chemicals from UCOs and UCOs-based glycerol

Application	Process	Product	Chemistry behind product use	Highlights	Ref.
UCOs Valorization					
Plasticizer	Transesterification of UCOs biodiesel with 2-ethylhexanol and further epoxidation	Epoxidized 2-ethylhexyl fatty ester	Oxirane reacts with compounds containing active hydrogen atoms (e.g. water, organic acids, alcohols, Halides)	Ep-WCOEtHEs in PVC enhanced the overall mechanical property and thermal stability, with no significant change in migration-resistant performance.	[34]
	Epoxidation	Epoxidized UCO	Enhanced thermo-oxidative stability by reducing unsaturations	Primary plasticizer for PVC films, without the need of other additives, resulting in samples with good thermal stability and mechanical properties	[35]
	Transesterification of UCO with methanol and epoxidation of methyl ester. Esterification with citric acid, and final acetylation with acetic anhydride	Acetylated FAME citric acid ester (Ac-FAME-CAE)	Hydrogen bonding of the 8 carboxylic groups of Ac-FAME-CAE with PVC polymer to enhance thermal stability	Similar plasticizing performance to DOP	[36]
	Epoxidation	Epoxidized UCO	Oxirane reacts with compounds containing active hydrogen atoms (e.g. water, organic acids, alcohols, Halides)	Homogeneous and heterogeneous catalysts were tested. Dimers and oligomers formed using H_2SO_4 as catalyst	[37]
	Esterification and transesterification with methanol and amino-methylation (Mannich reaction)	Mannich base of UCO biodiesel	chlorine atoms of PVC substituted with Mannich base of UCO biodiesel	Lower thermal stability due to the content of active secondary amine group	[38]
Asphalt/paveme nt binder	Drop-in. 5%wt. addition	Asphalt binder with light components from UCO	Carbonyl groups reacting with binders	Low temperature crack resistance and softness of the asphalt binder are improved	[39]
	Drop-in. 0.4 - 0.8 %wt. addition	Macadam pavement	UCO physically cover aggregates	Improves cracking and fatigue resistance	[40]
	Co-pyrolysis of UCO with rubber	Rubber/UCO binder	UCO reacts with rubber polymers during de-sulfurization and pyrolysis	Improved low temperature properties of binder Improved rheological properties of asphalt	[41, 42]
	Drop-in. 5%wt. addition	Binder replacement	Unsaturations bond with asphalt macromolecules and binder	Treated waste cooking oil can be used as a replacement of asphalt binder in asphalt mixtures	[43, 44]
	Drop-in. 5% UCO addition	Asphalt binder	Rheological modifier of asphalt binder	Addition of waste cooking oil as binder replacement was improve the durability performance of asphalt mixture.	[45]
Masonry binder	Drop-in. 10%wt. addition	Construction block	Oxy-polymerization and crosslinking	WasteVege block does not require the use of any form of cementitious or pozzolanic materials or water.	[46]

Epoxidized biodiesel	Enzymatic transesterification and epoxidation	Epoxidized UCO biodiesel	Oxirane reacts with compounds containing active hydrogen atoms (e.g. water, organic acids, alcohols, Halides)	Impurities had a negative effect in the epoxidation. Oxirane value 2.5.	[47]
Polyol / Polyurethane	Epoxidation of UCO and hydroxylation with diethylene glycol	UCO-based polyol	Hydroxyl groups react with isocyanate to form urethane bonds	The application of sulfuric acid in this experiment required a much higher temperature than in the case of the catalysts based on tetrafluoroboric acid and a longer reaction time. Satisfactory polyurethane bio-foams can be produced by replacing 40-60% of polyol with biobased alternative	[48, 49, 50]
Lubricant	Epoxidation and hydroxylation with methanol, ethanol, and 2-ethyl hexanol, esterification with hexanoic anhydride	UCO and UCO FAME poliol hexanoic ester	Enhanced thermo-oxidative stability by reducing unsaturations and hydroxyl groups	Products are compliant to standard lubricant specifications in terms of viscosity, viscosity index and pour point; with much higher biodegradability	[51]
	Epoxidation of UCO	Epoxidized UCO	Enhanced thermo-oxidative stability by reducing unsaturations	Epoxidized UCO exhibit highly desirable and enhanced physicochemical properties in all the aspects for environmentally friendly biolubricants.	[52]
	Enzymatic hydrolysis and esterification	Fatty acid neopentyl glycol ester	Enhance lubricity taking into account viscosity profile	A maximum conversion of 94% was found after 24 h using immobilized enzyme	[53]
	Drop-in. 15%wt. addition	UCO dispersible Cu nanoparticles	Unsaturations complexed on the nanoparticles surface.	Particles are synthesized in UCO, and directly used as additive. The formulations are stable, without segregation even after months.	[54]
Surfactant	Transesterification with methanol, sulfonation of methyl ester, and neutralization with NaOH	Methyl ester sodium sulfonate	Sulfonation provides polar moieties to FAME turning it into surfactant	Yield of methyl ester sulfonic acid (MESA) after sulfonation was obtained 77.20%. Methanol reduced substitution of methyl groups into a disalt	[55]
	Saponification of UCO with KOH, Acidification to FA, esterification with methanol to FAME, reduction to Fatty alcohol, esterification with chloroacetic acid, and amination	Diaminium chloride gemini-surfactant	Negatively charged carbonylic oxygen and chloride from surfactant are adsorbed on metal surface creating a protecting barrier layer	Efficacious inhibitor for steel (N80) corrosion	[56]
Liquid detergent	Transesterification with methanol and sulfonation of methyl ester	Methyl ester sulfonate	Sulfonation provides polar moieties to FAME turning it into surfactant	Liquid detergent comprising of 15% MES concentration and 0.1% ZnO nanoparticles	[57]
Biopolymer precursors	Transesterification and ethenolysis	Ethenolyzed and self-metathesized products	Olefinic bonds in reaction products can be used for further polymerization	A novel renewable lipidic source of spent hen for ethenolysis is exploited for the first time	[58]

Biobased Polymers	Epoxidation, hydroxylation with water, polymerization with Methylene diphenyl diisocyanate	UCO-based polyurethane doped with lithium iodide	Hydroxyl groups react with isocyanate to form urethane bonds	UCO-based PU could be used as a potential host for polymer electrolyte	[59]
	Fermentation	Polyhydroxyalkanoate and astaxanthin-rich carotenoids	Biodegradable, elastomeric, thermoplastic and biocompatible polymer	1% v/v UCO was used. 1 g/L of PHA	[60]
	Fermentation	Polyhydroxybutyrate [P(3HB)]		WCO could provide better accumulation of P(3HB) in *C. necator* H16 compared to other common plant-based oil. The higher production of P(3HB) was approximately 80 wt%.	[61]
	Fermentation	polyhydroxyalkanoates (PHAs) - (R)-3 hydroxyoctanoic acid and (R)-3-hydroxydecanoic acid monomers		Low molecular weight 18342 kDa, Low yields probably caused by inhibitory compounds in UCO	[62]
Fermentation supplement	Drop-in. 2-3%wt. addition	Microbial oil	Carbon source for biomass	Mixture of UCO with crude glycerol enhances oil accumulation in yeast	[63]
	Fermentation	Lipase		maximum lipase activity (12 000U/L), also lipid-rich biomass (48% of lipids mass per dry cellular mass),	[64]
	Fermentation	d- and l-Limonene		UCO is superior substrate than glucose, but low titers obtained 2.5-2.7 mg/L	[65]
Structured materials	Double thermal chemical vapor deposition	Graphene	Pyrolysed UCO is a carbon source for graphene formation	Utilization of UCO as the carbon source for the formation of multilayer graphene has been successfully performed.	[66]
3D printing resin	Acrylation	Triacylglycerol acrylate	UV-promoted crosslinking of acrylic moieties in acrylated UCO	Higher biodegradability of printed plastics, no photo inhibitors required	[67]
Emulsion liquid membrane	Drop-in. 50-80%wt. addition	Emulsion	UCO is used as organic solvent of liquid emulsion	99.1 efficiency in the recovery of organic dyes from contaminated water	[68]
Flotation oil	Pyrolysis	Deoxygenated hydrocarbons	Adsorption of hydrocarbons on coal surface	UCO pyrolysis products possessed strong collecting ability and better selectivity, and can replace diesel as a coal flotation collector.	[69]
Bioadsorbent	Impregnation and pyrolysis	Ordered micro-mesoporous carbon nanocasted on HZSM-5/SBA-15	Carbonaceous material contains oxygen-rich groups suitable for adsorption of cationic dyes. Ordered micro-mesoporous structure combines size selectivity and high diffusion rates	Material exhibits high adsorption capacity comparable to activated carbons	[70]

UCOs-based Glycerol valorization					
Carbon source	Fermentation	Hydrogen	Biobased building blocks	Bioconversion of crude glycerol by sub-tropical mixed and pure cultures. 15.14 moL H_2/mol glycerol	[71]
		Lactic acid		Bioconversion to lactic acid by *Rhizopus microsporus*. Lactic acid average production of 3.99 g/L	[72]
		1,3 Propanediol		The effect of crude glycerol impurities on 1,3-propanediol biosynthesis by *Klebsiella pneumoniae DSMZ* 2026. 9.69 g/L 1,3-PD (yield 0.21 g/g, productivity 0.80 g/L/h) was obtained after 12 h	[73]
		1,3 Propanediol		Production to 1,3-Propanediol and Lactate by a Microbial Consortium. Impurities in GWCO did pose a great challenge to microbial growth and metabolism. In fed batch fermentation, 27.77 g/L 1,3-PDO and 14.68 g/L LA were achieved.	[74]
		Valeric acid		Anaerobic fermentation with open microbiome. High valerate extraction rates with medium and maximum values of 12.9 and 30.0 g COD /m3 day, were obtained with low ethanol addition (15% of the glycerol-COD)	[75]
		1,3 Propanediol		1,3-PDO production with a mixed culture, A maximum productivity of 7.49 g/Ld	[76]
		Lipids		Lipid production via fermentation with *Trichosporon oleaginosus*. The highest lipid yield 0.19 g/g glycerol was obtained at 50 g/L purified glycerol in which the biomass concentration and lipid content were 10.75 g/L and 47% w/w, respectively.	[77]
		Citric acid, Succinic acid		A Suitable Substrate for the Growth of *Candida zeylanoides* Yeast Strain ATCC 20367. Biosynthesis of organic acids (e.g., citric 0.66 g/L; and succinic, 0.6 g/L) was significantly lower compared to pure glycerol and glucose used as main carbon sources.	[78]

4. Challenges and future directions

As observed, UCOs can be used as raw material for a large variety of green chemicals. In addition to the technical limitations observed in some of the processes, there are a number of issues that need to be overcome in order to enable industrial implementation. As in any other biorefinery, the supply chain plays a major role in the sustainability of the proposed production schemes. In this case, a major fraction of the generated UCOs comes from the Household segment, for which very low recovery efficiencies are typical (< 6%, [11]). Hence, it is necessary to deploy effective policies and regulated practices to enhance UCOs recycling and collection rates, under multi-stakeholders considerations (i.e. authorities, generators, collecting companies, biorefineries). This also indicates that there is need to optimize the collection schemes to ensure that the consumed resources (e.g. energy, financial) do not surpass those from the obtained UCOs, mainly when the biorefineries operate as centralized facilities far from the source. For instance, one study has shown that from a life cycle perspective, biodiesel from European rapeseed UCOs is less sustainable than petroleum diesel and even less than biodiesel from Indonesian's palm oil UCOs [18].

Another major challenge is the highly heterogeneous nature of UCOs. They exhibit a large variability in physicochemical and sensory properties, and a substantial amount of impurities [8, 79, 80], resulting from different diets, culinary practices, and management procedures. In most of the studied processes of Table 1 there were reports of impurities in the raw material affecting the catalytic and biologically conversion steps, the drop-in uses, and even the thermochemical transformations. Also, unpleasant sensory properties (e.g. color, appearance, odour) are of major concern. Therefore, suitable upgrading processes must be implemented to enable the efficient transformation of UCOs to the desired biobased chemicals without compromising the economic feasibility [81]. Also, resilient and intensified technologies must be developed to enable the use of other types of waste lipids (e.g. trap grease, rancid oils, food/solid waste lipids, etc.). In any case, even after pretreatment and upgrading, the presence of trace impurities also might prevent that some of the derivatives could be used in sensitive applications (e.g. personal care products, cosmetics, food or pharmaceuticals) where the market is more attractive. Alternatively, they could be directed to other markets such as construction materials, asphalt, rubbers, lubricants, surfactants, fuels, etc.

A current threat to the industrial implementation of UCOs-based chemicals, is that they are strongly linked to the biodiesel market, and there are some concerns about the sustainability of this fuel especially given the rapid move from liquid fuel to electric-powered vehicles. Nowadays, UCOs biodiesel is promoted via public policies such as the Renewable Energy Directive (RED II) from EU. According to this directive, UCO biodiesel can be double-counted, so its price can be higher than first generation biodiesel, encouraging supply and demand. Nevertheless, recent claims indicate that at least one-third of UCO-based biodiesel in the European market is fraudulent, because apparently it corresponds to the recently banned palm oil biodiesel [82]. Besides, some of the unsustainable palm oil that was prohibited in the EU has been diverted to China for animal feed in order to replace the UCOs that are currently exported to Europe [83]. These type of problems might push for revisions of RED II, which will directly affect UCOs supply for the oleochemical industry [84]. Finally, current COVID-19 pandemic is putting pressure on UCOs global trading, affecting supply, dropping prices, and reducing the potential profitability of the biorefineries [85].

5. Concluding Remarks

Used Cooking Oil is a valuable food waste that can be transformed into a large variety of products. While the use as biofuel feedstock enabled the creation of a global collection and supply chain of UCOs, only the incorporation of high value added green chemicals within the biorefineries would ensure their long-term sustainability. As presented, UCOs exploitation as oleochemical feedstock can involve large reductions in life cycle impacts, cutting the need for virgin vegetable oil, and alleviating the impacts of the current mismanaging practices for disposal. Also, by using UCO derivatives as ingredients in different end products, there is a contribution to "green" other sectors such as polymers, asphalts, cementing materials, detergents, lubricants, etc. Despite such a circular economy model around UCO seeming attractive, major challenges have to be overcome. Future developments will be mostly focused on dealing with UCOs heterogeneity and impurities content, upgrading processes, enhancing household collection, and implementing resilient and intensified processes capable of incorporating different types of waste lipids (e.g. trap grease, rancid oils, solid waste lipids, etc.).

Conflict of interest statement

Nothing declared.

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References

Papers of particular interest are highlighted as:

* of special interest
* * of outstanding interest

[1] Caldeira, C., Corrado, S. Sala, S., Food waste accounting - Methodologies, challenges and opportunities, EUR 28988 EN; Luxembourg (Luxembourg): Publications Office of the European Union; 2017. JRC109202, DOI: 10.2760/54845

[2] The economist. Food Sustainability Index 2017. https://foodsustainability.eiu.com/ [accessed March 20, 2020]

[3] ** Dahiya, S., Kumar, A. N., Sravan, J. S., Chatterjee, S., Sarkar, O., Mohan, S. V. Food waste biorefinery: Sustainable strategy for circular bioeconomy. *Bioresour. Technol.* 2018, **248**: 2–12. DOI: 10.1016/j.biortech.2017.07.176

A current state of the art of potential approaches for valorization of different food waste through circular economy models, including UCOs.

[4] * Carmona-Cabello, M., Garcia, I. L., Leiva-Candia, D., Dorado, M. P. Valorization of food waste based on its composition through the concept of biorefinery. *Curr. Opin. Green Sustain. Chem.* 2018, **14**: 67–79. DOI: 10.1016/j.cogsc.2018.06.011

The status of food waste biorefineries, potential feedstock and key value-added products

[5] ** Lin, C. S. K., Pfaltzgraff, L. A., Herrero-Davila, L., Mubofu, E. B., Abderrahim, S., Clark, J. H., Koutinas, A. A., Kopsahelis, N., Stamatelatou, K., Dickson, F., Thankappan, S., Mohamed, Z., Brocklesbyc, R., Luque, R. Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. *Energy Environ. Sci.* 2013, **6**: 426–464. DOI: 10.1039/c2ee23440h

A well-accomplished general overview of innovative uses of food waste for the synthesis of value-added products, including the analysis of supply chain, policies, regulations and a road map for future developments.

[6] Carmona-Cabello, M., García, I. L., Sáez-Bastante,J., Pinzi, S., Koutinas, A. A., Dorado, M. P. Food waste from restaurant sector – Characterization for biorefinery approach. *Bioresour. Technol.* 2020, **301**: 122779. DOI: 10.1016/j.biortech.2020.122779

[7] Salimi, E., Taheri, M. E., Passadis, K., Novacovic, J., Barampouti, E. M., Mai1, S., Moustakas, K., Malamis, D., Loizidou, M. Valorisation of restaurant food waste under the concept of a biorefinery. Biomass Conversion and Biorefinery. 2020. In press. DOI: /10.1007/s13399-020-00613-4

[8] Rincón, L. A., Cadavid, J. G., Orjuela, A. Used cooking oils as potential oleochemical feedstock for urban biorefineries – Study case in Bogota, Colombia. *Waste Manage.* 2019, **88**: 200–210. DOI: 10.1016/j.wasman.2019.03.042

[9] ** Orjuela, A. Industrial Oleochemicals from Used Cooking Oils (UCOs) – Sustainability Benefits and Challenges. Orjuela A. In: Advances in Carbon Management Technologies, Vol 2. Ch. 5., Eds. Sikdar, S., Princiotta, F. CRC Press. 2020.

This work presents a description of major challenges on UCOs supply, management and processing. The corresponding physicochemical properties are correlated with the potential uses for higher value-added oleochemicals. Current industrial uses are described.

[10] Garner, K. (Ed.) Recycled Cooking Oil: Processing and Uses. Nova Science Publishers 2018.

[11] Greenea, 2016. Analysis of the current development of household UCO collection systems in the EU. 2016.https://theicct.org/sites/default/files/publications/Greenea%20Report%20Household%20UCO%20Collection%20in%20the%20EU_ICCT_20160629.pdf [accessed March 20, 2020].

[12] Greenea, 2018. And do you recycle your used cooking oil at home?. 2018. https://www.greenea.com/wp-content/uploads/2017/03/Greenea-article-UCO-household-collection-2017.pdf [accessed March 20, 2020].

[13] ** Ribau, M., Nogueira, R., Miguel, L. Quantitative assessment of the valorisation of used cooking oils in 23 countries. *Waste Manage.* 2018, **78**: 611-20. DOI: 10.1016/j.wasman.2018.06.039

A correlation between vegetable oil consumption and UCO generation was developed in a global scale. The amount of valorized UCOs was estimated for different countries.

[14] MRF. Used Cooking Oil (UCO) Market Research Report - Global Forecast till 2025. https://www.marketresearchfuture.com/reports/used-cooking-oil-market-4516 [accessed March 20, 2020].

[15] Greenea. Market & Analysis. 2020. http://www.greenea.com/en/market-analysis/ [accessed March 20, 2020].

[16] OECD. OECD-FAO Agricultural Outlook 2019-2028. 2019. Available at: https://stats.oecd.org [accessed March 20, 2020]

[17] Vinyes, E., Oliver-Solà, J., Ugaya, C., Rieradevall, J., Gasol, C. M. Application of LCSA to used cooking oil waste management. Int. J. Life Cycle Assess. 2013, **18**: 445–455. DOI: 10.1007/s11367-012-0482-z

[18] Behrends, F. J. Greenhouse gas footprint of biodiesel production from used cooking oils. Doctoral dissertation. Utrecht University. 2018.

[19] Torres, P. 2019. Life cycle assessment of the exploitation and valorization of used cooking oil in Bogotá as oleochemical feedstock (In Spanish). Master's Dissertation. National University of Colombia, 2019.

[20] Chrysikou, L. P., Dagonikou, V., Dimitriadis, A., Bezergianni, S. Waste cooking oils exploitation targeting EU 2020 diesel fuel production: Environmental and economic benefits. *J. Clean. Prod.* 2019, **219**: 566-575. DOI: 10.1016/j.jclepro.2019.01.211

[21] ** Hatzisymeon, M., Kamenopoulos, S., Tsoutsos, T. Risk assessment of the life-cycle of the Used Cooking Oil-to-biodiesel supply chain. *J. Clean. Prod.* 2019, **217**: 836-843. DOI: 10.1016/j.jclepro.2019.01.088

Risk assessment in the UCOs exploitation chain, considering the impacts of accidents during collection and road transport. The economic and social impacts are also considered.

[22] Foteinis, S., Chatzisymeon, E., Litinas, A., Tsoutsos, T. Used-cooking-oil biodiesel: Life cycle assessment and comparison with first- and third-generation biofuel, *Renew. Energy*, 2020. In press. DOI: 10.1016/j.renene.2020.02.022

[23] Greenea. 2016a. Waste-based feedstock and biofuels market in Europe. 2016. Available at https://www.greenea.com/wp-content/uploads/2016/11/Argus-2016.pdf [accessed March 20, 2020].

[24] SCOPUS. Elsevier. 2020. https://www.scopus.com/search/form.uri?display=basic [accessed March 20, 2020]

[25] USPTO. United States Patent and Trademark Office. http://patft.uspto.gov/netahtml/PTO/index.html [accessed march, 20, 2020]

[26] WIPO. World intellectual Property Organization. Geneva, Switzerland. https://patentscope.wipo.int [accessed March. 20, 2020]

[27] Bioplastics magazine.com , «Newest market and trend report: 2018 was a very good year for bio-based polymers.,» 2019. https://www.bioplasticsmagazine.com/en/news/meldungen/20190220Newest-market-and-trend-report---2018-was-a-very-good-year-fo--bio-based-polymers.php. [accessed March 20, 2020].

[28] Singh, Y., Sharma, A., Singla, A. Non-edible vegetable oil–based feedstocks capable of bio-lubricant production for automotive sector applications—a review. *Environ. Sci. Pollut. Res.* 2019, **26**: 14867–14882. DOI: 10.1007/s11356-019-05000-9

[29] ** Lopes, M., Miranda, S. M., Belo, I. Microbial valorization of waste cooking oils for valuable compounds production – a review. *Crit. Rev. Env. Sci. Tec.* 2020. In Press DOI: 10.1080/10643389.2019.1704602

A Comprehensive review of microbial pathways for UCOs exploitation identifying active microbial species and the respective chemical derivatives.

[30] * Zaharudin, N. A., Rashid, R., Esivan, S. M. M., Othman, N., Idris, A. Review on the potential use of waste cooking palm oil in the production of high oleic palm oil via enzymatic acidolysis. *J. Teknol.* 2016, **78** (6–12): 85–99. DOI: 10.11113/jt.v78.9237

Revision of current potential alternatives for palm oil UCO transformation into structured lipids

[31] * Ahmed, R. B., Hossain, K. Waste cooking oil as an asphalt rejuvenator: A state-of-the-art review. *Constr. Build. Mater.* 2020, **230**: 116985. DOI: 10.1016/j.conbuildmat.2019.116985

A detailed description of most current developments in the use of UCO as asphal rejuvenator

[32] * Luo, X., Ge, X., Cui, S., Li, Y. Value-added processing of crude glycerol into chemicals and polymers. *Bioresour Technol.* 2016, **215**: 144–154. DOI: 10.1016/j.biortech.2016.03.042

A Review Value-added processing of crude glycerol into chemicals and polymers via biological or chemical conversion, including UCOs-based glycerol.

[33] * Chen, J., Yan, S., Zhang, X., Tyagi, R. D., Surampalli, R. Y., Valéro, J. Chemical and biological conversion of crude glycerol derived from waste cooking oil to biodiesel. *Bioresour Technol.* 2019, **293**, 122155. DOI: 10.1016/j.biortech.2019.122155

A study of crude glycerol composition and bio-valorization as carbon source for lipids production

[34] Zheng, T., Wu, Z., Xie, Q., Fang, J., Hu, Y., Lu, M., Xia, F., Nie, Y., Ji, J. Structural modification of waste cooking oil methyl esters as cleaner plasticizer to substitute toxic dioctyl phthalate. *J. Clean. Prod.* 2018, **186**: 1021-1030. DOI: 10.1016/j.jclepro.2018.03.175

[35] Suzukia, A. H., Botelho, B. G., Oliveira, L. S., Franca, A. S. Sustainable synthesis of epoxidized waste cooking oil and its application as a plasticizer for polyvinyl chloride films. *Eur. Polym. J.* 2018, **99**: 142–149. DOI: 10.1016/j.eurpolymj.2017.12.014

[36] Feng, G., Hu, L., Ma, Y., Jia, P., Hu, Y., Zhanga, M., Liu, C., Zhou, Y. An efficient bio-based plasticizer for poly (vinyl chloride) from waste cooking oil and citric acid: Synthesis and evaluation in PVC films. *J. Clean. Prod.* 2018, **189**: 334-343. DOI: 10.1016/j.jclepro.2018.04.085

[37] Kurańska, M., Beneš, H., Prociak, A., Trhlíková, O., Walterová, Z., Stochlińska, W. Investigation of epoxidation of used cooking oils with homogeneous and heterogeneous catalysts. *J. Clean. Prod.* 2019, **236**: 117615. DOI: 10.1016/j.jclepro.2019.117615

[38] Jia, P.; Zhang, M.; Hu, L.; Song, F.; Feng, G.; Zhou, Y. A strategy for nonmigrating plasticized PVC modified with mannich base of waste cooking oil methyl ester. *Sci. Rep.* 2018, **8**: 1589. DOI: 10.1038/s41598-018-19958-y

[39] Cong, P., Chen, B., Zhao, H. Coupling effects of wasted cooking oil and antioxidant on aging of asphalt binders. *Int. J. Pavement Res. Technol.* 2020, **13**: 64–74. DOI: 10.1007/s42947-019-0086-0

[40] Li, X., Lv, X., Wang, W., Liu, J., Yu, M., You, Z. Crack resistance of waste cooking oil modified cement stabilized macadam. *J. Clean Prod.* 2020, **243**: 118525. DOI: 10.1016/j.jclepro.2019.118525

[41] Xingyu, Y., Ruikun, D., Naipeng, T. Development of a novel binder rejuvenator composed by waste cooking oil and crumb tire rubber. *Constr. Build. Mater.* 2020, **236**: 117621. DOI: 10.1016/j.conbuildmat.2019.117621

[42] Dong, R., Zhao, M. Research on the pyrolysis process of crumb tire rubber in waste cooking oil. *Renew. Energy* 2018, **125**: 557-567. DOI: 10.1016/j.renene.2018.02.133

[43] Jaya, R. P., Lopa, R. S., Hassan, N. A., Yaacob, H., Ali, M. I., Hamid, N. H. A., Abdullah, M. E. Performance of Waste Cooking Oil on Aged Asphalt Mixture. *E3S Web Conf. ICCEE* 2018, **65**: 02002. DOI: 10.1051/e3sconf/20186502002

[44] * Cong, P.L., Hao, H. J., Luo, W. H. Investigation of carbonyl of asphalt binders containing antiaging agents and waste cooking oil using FTIR spectroscopy. *J. Test. Eval.* 2019, 47 (2): 1147-1162. DOI: 10.1520/JTE20180146

This work try to elucidate the physicochemical action of UCOs in asphalt binders

[45] Ramadhansyah, P. J., Azman, M. K., Idris, A. M., Aifa, W. A. W. N., Ekarizan, S., Hainin, M. R., Norhidayah, A. H., Haryati, Y. Voids Characteristic of Hot Mix Asphalt Containing Waste Cooking Oil *IOP Conf. Series: Earth and Environ. Sci.* 2019, **244**: 012049. DOI: 10.1088/1755-1315/244/1/012049

[46] Adebayo, J. O., Napiah, M., Ibrahim, K., Kabit, M. R. Evaluation of Waste Cooking Oil as Sustainable Binder for Building Blocks. *E3S Web Conf. ICCEE* 2018, **65**: 05003. DOI: 10.1051/e3sconf/20186505003

[47] Wang, J., Zhao, X., Liu, D. Preparation of Epoxidized Fatty Acid Methyl Ester with in situ Auto-Catalyzed Generation of Performic Acid and the Influence of Impurities on Epoxidation. *Waste Biomass Valor*. 2018, **9**: 1881–1891. DOI: 10.1007/s12649-017-9945-6

[48] Kuranska, M., Benes, H., Polaczek, K., Trhlikova, O., Walterova, Z., Prociak, A. Effect of homogeneous catalysts on ring opening reactions of epoxidized cooking oils. *J. Clean. Prod.* 2019, **230**: 162-169. DOI: 10.1016/j.jclepro.2019.05.096

[49] Kurańska, M., Polaczek, K., Auguścik-Królikowska, M., Prociak, A., Ryszkowska, J. Open-cell rigid polyurethane bio-foams based on modified used cooking oil. *Polymer* 2020, **190**: 122164. DOI: 10.1016/j.polymer.2020.122164

[50] Kurańska, M., Polaczek, K., Auguścik-Królikowska, M., Prociak, A., Ryszkowska, J. Open cell polyurethane foams based on modified used cooking oil. *Polimery* 2020, **65**: 52–61. DOI: 10.14314/polimery.2020.3.7

[51] Borugadda, V. B., Goud, V. V. Hydroxylation and hexanoylation of epoxidized waste cooking oil and epoxidized waste cooking oil methyl esters: Process optimization and physico-chemical characterization. *Ind. Crop. Prod.* 2019, **133**: 151–159. DOI: 10.1007/s12649-015-9434-8

[52] Paul, A. K., Borugadda, V. B., Bhalerao, M. S., Goud, V. V. In situ epoxidation of waste soybean cooking oil for synthesis of biolubricant basestock: A process parameter optimization and comparison with RSM, ANN, and GA. *Can. J. Chem. Eng.* 2018, **96**: 1451–1461. DOI: 10.1002/cjce.23091

[53] Sarno, M., Luliano, M., Cirillo, C. Optimized procedure for the preparation of an enzymatic nanocatalyst to produce a bio-lubricant from waste cooking oil. *Chem. Eng. J.* 2019, **377**, 120273. DOI: 10.1016/j.cej.2018.10.210

[54] Sarno, M., Spina, D., Senatore, A. One-step nanohybrid synthesis in waste cooking oil, for direct lower environmental impact and stable lubricant formulation. *Tribol. Int.* 2019, **135**: 355–367. DOI: 10.1016/j.triboint.2019.03.025

[55] Permadani, R. L., Ibadurrohman, M., Slamet, S. Utilization of waste cooking oil as raw material for synthesis of Methyl Ester Sulfonates (MES) surfactant. *J. Surfactants Deterg.* 2016, **19**: 467-475. DOI: 10.1088/1755-1315/105/1/012036

[56] Khalaf, M. M., Tantawy, A. H., Soliman, K. A., El-Lateef, H. M. A. Cationic gemini-surfactants based on waste cooking oil as new ‘green’ inhibitors for N80-steel corrosion in sulphuric acid: A combined empirical and theoretical approaches. *J. Mol. Struct.* 2020, **1203**: 127442. DOI: 10.1016/j.molstruc.2019.127442

[57] Junior, G. D., Ibadurrohman, M., Slamet, S. Synthesis of eco-friendly liquid detergent from waste cooking oil and ZnO nanoparticles. *AIP Conf. Proc.* 2019, **2085**, 020075. DOI: 10.1063/1.5095053

[58] Pradhan, R. A., Arshad, M., Ullah, A. Solvent-free rapid ethenolysis of fatty esters from spent hen and other lipidic feedstock with high turnover numbers. *J. Ind. Eng. Chem.* 2020, **84**: 42-45. DOI: 10.1016/j.jiec.2020.01.002

[59] Salleh, W.N.F.W., Tahir, S. M., Mohamed, N. S. Synthesis of waste cooking oil-based polyurethane for solid polymer electrolyte. *Polym. Bull.* 2018, **75**: 109–120. DOI: 10.1007/s00289-017-2019-x

[60] Koller, M. Linking Food Industry to “Green Plastics” – Polyhydroxyalkanoate (PHA) Biopolyesters from Agro-industrial By-Products for Securing Food Safety. *Appl. Food Biotechnol.* 2019, **6** (1):53-60. DOI: 10.22037/afb.v6i1.21628

[61] Kamilah, H., Al-Gheethi, A., Yang, T. A., Sudesh, K. The Use of Palm Oil-Based Waste Cooking Oil to Enhance the Production of Polyhydroxybutyrate [P(3HB)] by Cupriavidus necator H16 Strain. *Arab. J. Sci. Eng.* 2018, **43**: 3453–3463. DOI: 10.1007/s13369-018-3118-1

[62] Ruiz, C., Kenny, S. T., Narancic, T., Babu, R., Connor, K. O. Conversion of waste cooking oil into medium chain polyhydroxyalkanoates in a high cell density fermentation. *J. Biotechnol.* 2019, **306**: 9–15. DOI: 10.1016/j.jbiotec.2019.08.020

[63] Yen, H. W., Hu, C. Y., Liang, W. S. A cost efficient way to obtain lipid accumulation in the oleaginous yeast Rhodotorula glutinis using supplemental waste cooking oils (WCO). *J. Taiwan Inst. Chem. Eng.* 2019, **97**: 80–87. DOI: 10.1016/j.jtice.2019.02.012

[64] Lopes, M., Miranda, S. M., Alves, J. M., Pereira, A. S., Belo, I. Waste Cooking Oils as Feedstock for Lipase and Lipid-Rich Biomass Production. *Eur. J. Lipid Sci. Technol.* 2019, **121**, 1800188. DOI: 10.1002/ejlt.201800188

[65] Pang, Y., Zhao, Y., Li, S., Zhao, Y., Li, J., Hu, Z., Zhang, C., Xiao, D., Yu, A. Engineering the oleaginous yeast Yarrowia lipolytica to produce limonene from waste cooking oil. *Biotechnol. Biofuels* 2019, **12**: 241. DOI: 10.1186/s13068-019-1580-y

[66] Mamat, R. H., Hamzah, F., Hashim, A., Abdullah, S., Alrokayan, A., Khan, H. A., Safiay, M., Jafar, S. M., Asli, A., Khusaimi, Z., Rusop, M. Influence of volume variety of waste cooking palm oil as carbon source on graphene growth through double thermal chemical vapor deposition. IEEE ICSE, 2018, 53-56. DOI: 10.1109/SMELEC.2018.8481302

[67] Wu, B., Sufi, A., Biswas, R. G., Hisatsune, A., Moxley-Paquette, V., Ning, P., Soong, R. Dicks, A. P., Simpson, A. J. Direct Conversion of McDonald’s Waste Cooking Oil into a Biodegradable High-Resolution 3D-Printing Resin. *ACS Sustain. Chem. Eng.* 2020, **8** (2): 1171-1177. DOI: 10.1021/acssuschemeng.9b06281

[68] Shokri, A., Daraei, P., Zereshki, S. Water decolorization using waste cooking oil: An optimized green emulsion liquid membrane by RSM. *J. Water Process. Eng.* 2020, **33**, 101021. DOI: 10.1016/j.jwpe.2019.101021

[69] Shen, L., Min, F., Liu, L., Zhu, J., Xue, C., Cai, C., Zhou, W., Wang, C. Application of gaseous pyrolysis products of the waste cooking oil as coal flotation collector. *Fuel* 2019, **239**: 446–451. DOI: 10.1016/j.fuel.2018.11.056

[70] Sobrinho, R. A. L., Andrade, G. R. S., Costa, L. P., de Souza, M. J. B., de Souza, A. M. G. P., Gimenez, I. F. Ordered micro-mesoporous carbon from palm oil cooking waste via nanocasting in HZSM-5/SBA-15 composite: Preparation and adsorption studies. *J. Hazard. Mater.* 2019, **362**: 53–61. DOI: 10.1016/j.jhazmat.2018.08.097

[71] Rodrigues C. V., Nespeca M. G., Sakamoto I. K., Oliveira J. E. D., Varesche M. B. A., Maintinguer S. I. Bioconversion of crude glycerol from waste cooking oils into hydrogen by sub-tropical mixed and pure cultures. *Int. J. Hydrogen Energ.* 2018, **44**: 144–154. DOI: 10.1016/j.ijhydene.2018.02.174

[72] Yuwa-Amornpitak, T., Chookietwatana, K. Bioconversion of waste cooking oil glycerol from cabbage extract to lactic acid by Rhizopus microsporus. Braz. J. Microbiol. 2018, **49**: Suppl. 178-184. DOI: 10.1016/j.bjm.2018.06.007

[73] Mitrea, L., Trif, M., Vodnar D. C. The effect of crude glycerol impurities on 1,3-propanediol biosynthesis by Klebsiella pneumoniae DSMZ 2026. *Renew. Energy* 2020, **153**: 1418-1427. DOI: 10.1016/j.renene.2020.02.108

[74] Wang, X. L., Zhou, J. J., Sun, Y. Q., Xiu, Z. L. Bioconversion of Raw Glycerol From Waste Cooking-Oil-Based Biodiesel Production to 1,3-Propanediol and Lactate by a Microbial Consortium. *Front. Bioeng. Biotechnol.* 2019, **7**: 14. DOI: 10.3389/fbioe.2019.00014

[75] Veras, S. T. S., Cavalcante, W. A., Gehring, T. A., Ribeiro, A. R., Ferreira, T. J. T., Kato, M. T., Rojas-Ojeda, P., Sanz-Martin, J. L., Leitão, R. C. Anaerobic production of valeric acid from crude glycerol via chain elongation. *Int. J. Environ. Sci. Technol.* 2020, **17**: 1847–1858. DOI: 10.1007/s13762-019-02562-6

[76] Veras, S. T. S., Rojas, P., Florencio, L., Kato, M. T., Sanz, J. L. Production of 1,3-propanediol from pure and crude glycerol using a UASB reactor with attached biomass in silicone support. *Bioresour. Technol.* 2019, **279**: 140–148. DOI: 10.1016/j.biortech.2019.01.125

[77] Chen, J., Yan, S., Zhang, X., Tyagi, R. D., Surampalli, R. Y., Valéro, J. R. Chemical and biological conversion of crude glycerol derived from waste cooking oil to biodiesel. *Waste Manage*. 2018, **71**: 164–175. DOI: 10.1016/j.wasman.2017.10.044

[78] Mitrea, L., Ranga, F., Fetea, F., Dulf, F. V., Rusu, A., Trif , M. Vodnar, D. C. Biodiesel-Derived Glycerol Obtained from Renewable Biomass—A Suitable Substrate for the Growth of Candida zeylanoides Yeast Strain ATCC 20367. *Microorganisms* 2019, **7**, 265. DOI: 10.3390/microorganisms7080265

[79] Siqueira, A.F., Melo, M.P., Giordani, D.S., Galhardi, D.R.V., Santos, B.B., Batista, P.S., Ferreira, A.L.G. Stochastic modeling of the transient regime of an electronic nose for waste cooking oil classification. *J. Food Eng.* 2018, **221**: 114-123.

[80] Mannu, A., Ferro, M., Colombo, G., Panzeri, W., Petretto, G. L., Urgeghe, P., Melea, A. Improving the recycling technology of waste cooking oils: Chemical fingerprint as tool for non-biodiesel application. *Waste Manage.* 2019, **96**: 1-8.

[81] Predojevic, Z. J. The production of biodiesel from waste frying oils: A comparison of different purification steps. Fuel 2008, **87**: 3522–3528.

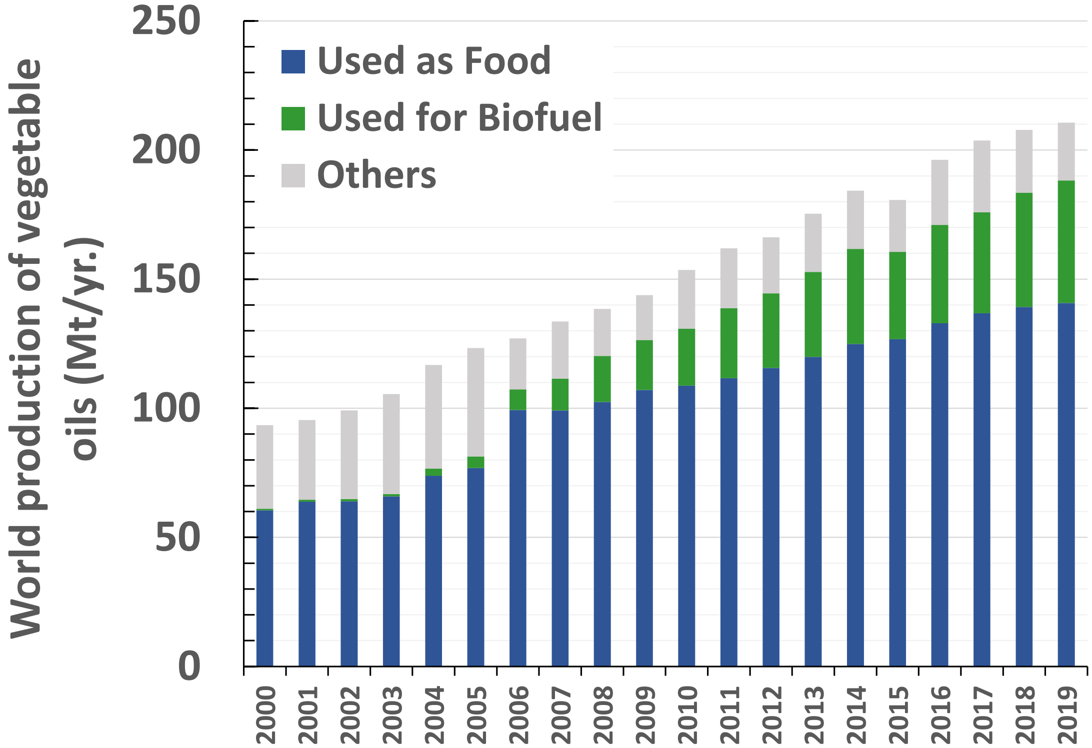
[82] Michalopoulos, S., Industry source: one third of used cooking oil in Europe is fraudulent. EURACTIV 2019. https://www.euractiv.com/section/all/news/industry-source-one-third-of-used-cooking-oil-in-europe-is-fraudulent/ [accessed March 20, 2020].

[83] Phillips, D. Implications of Imported Used Cooking Oil (UCO) as a Biodiesel Feedstock. NNFCC, 2019. Available at: https://www.nnfcc.co.uk/files/mydocs/UCO%20Report.pdf [accessed March 20, 2020].

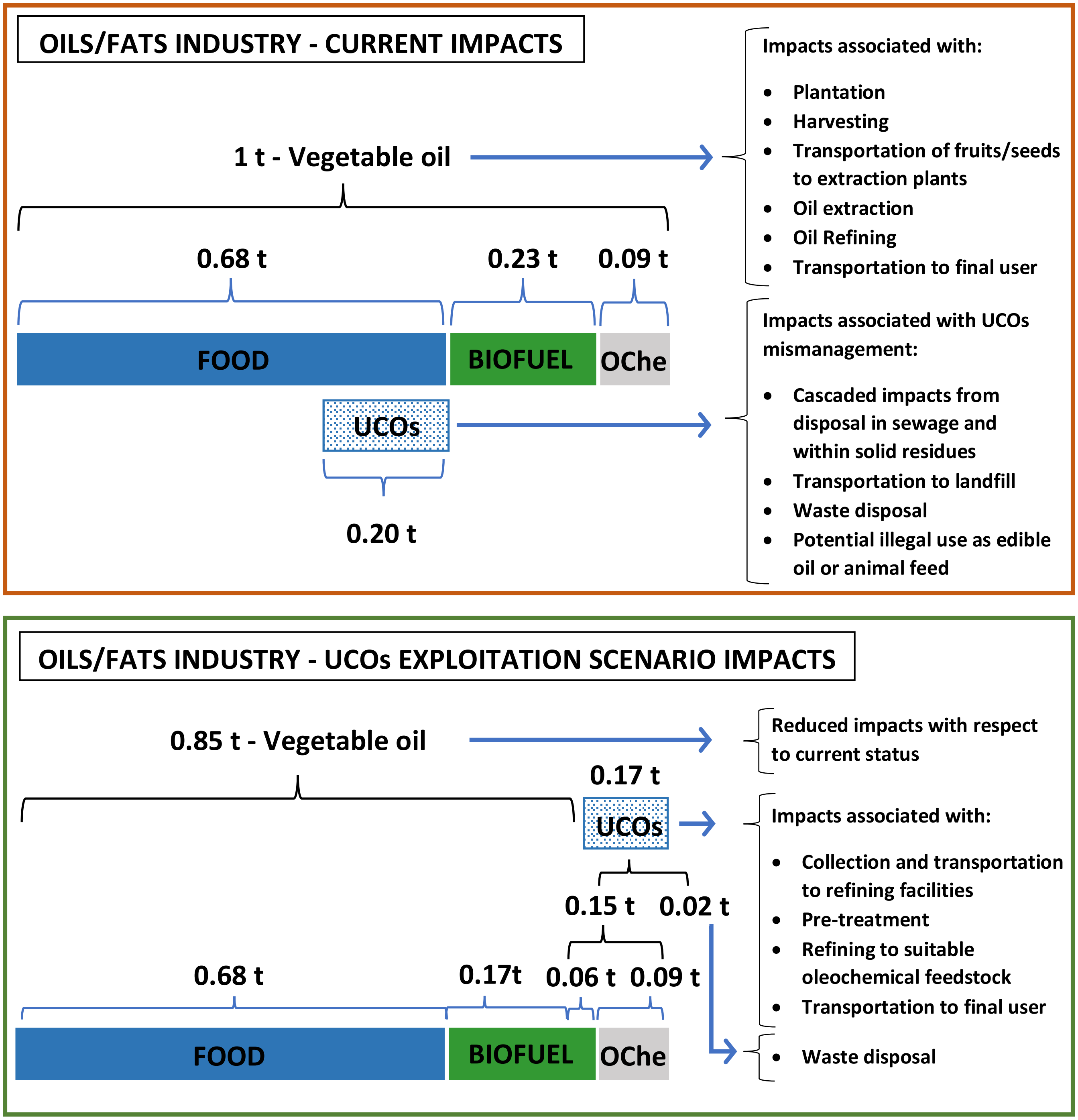
[84] Michalopoulos, S. Netherlands mulls end to used cooking oil double-counting. EURACTIV 2019. https://www.euractiv.com/section/agriculture-food/news/the-netherlands-mulls-end-to-used-cooking-oil-double-counting/ [accessed March 20, 2020].

[85] Greenea. COVID-19: A hard blow for UCO. 2020. https://www.greenea.com/wp-content/uploads/2020/03/COVID-19-A-hard-blow-for-UCO-March-2020.pdf [accessed March 20, 2020].

Figure

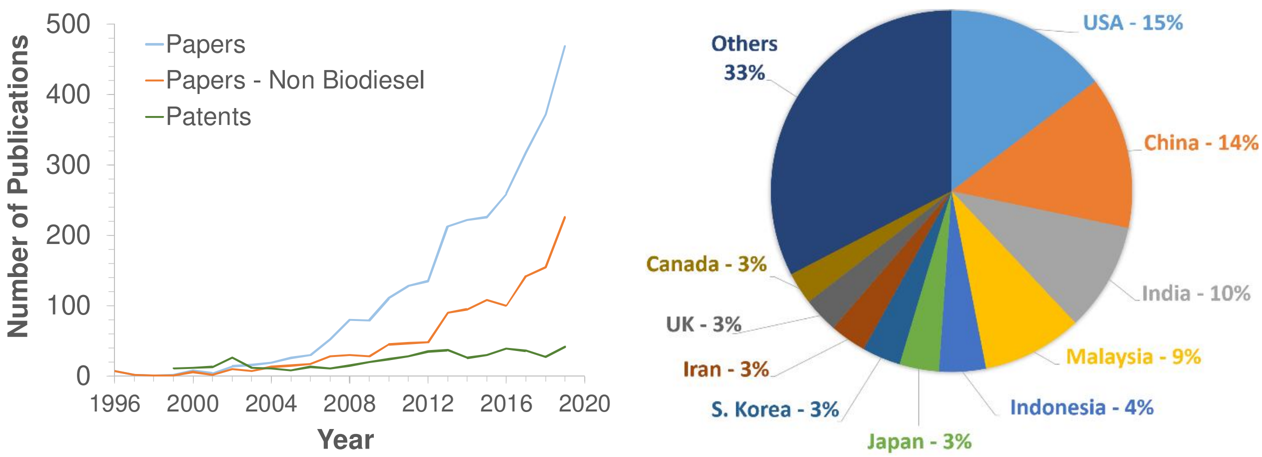

World production of vegetable oils (Mt/yr.)
Used as Food
Used for Biofuel
Others
0
50
100
150
200
250
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure



OILS/FATS INDUSTRY - CURRENT IMPACTS
1 t - Vegetable oil
0.68 t
0.23 t
0.09 t
FOOD
BIOFUEL
OChe
UCOs
0.20 t
Impacts associated with:
Plantation
Harvesting
Transportation of fruits/seeds to extraction plants
Oil extraction
Oil Refining
Transportation to final user
Impacts associated with UCOs mismanagement:
Cascaded impacts from disposal in sewage and within solid residues
Transportation to landfill
Waste disposal
Potential illegal use as edible oil or animal feed
OILS/FATS INDUSTRY - UCOs EXPLOITATION SCENARIO IMPACTS
0.85 t - Vegetable oil
0.17 t
UCOs
0.15 t
0.02 t
0.68 t
0.17t
0.06 t
0.09 t
FOOD
BIOFUEL
OChe
Reduced impacts with respect to current status
Impacts associated with:
Collection and transportation to refining facilities
Pre-treatment
Refining to suitable oleochemical feedstock
Transportation to final user
Waste disposal

Figure


Number of Publications
500
400
300
200
100
0
Papers
Papers - Non Biodiesel
Patents
1996
2000
2004
2008
2012
2016
2020
Year
USA - 15%
China - 14%
India - 10%
Malaysia - 9%
Indonesia - 4%
Japan - 3%
S. Korea - 3%
Iran - 3%
UK - 3%
Canada - 3%
Others
33%

HIGHLIGHTS

- World production of used cooking oils (UCOs) and current market data
- Identification of life cycle impacts reduction by exploitation of UCOs
- Review of current state of art on used cooking oil valorisation into green chemicals
- Major challenges on UCOs utilization as oleochemical feedstock