Waste Management 78 (2018) 611–620

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Review

Quantitative assessment of the valorisation of used cooking oils in 23 countries

Margarida Ribau Teixeira [a], Ricardo Nogueira [b], Luís Miguel Nunes [c,*]

[a] CENSE, Center for Environmental and Sustainability Research, and Faculty of Sciences and Technology, University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
[b] Hidrognosis, Ambiente e Recursos Hídricos, Avenida da República, 54, 8000-079 Faro, Portugal
[c] CERIS, Civil Engineering Research and Innovation For Sustainability, Faculty of Sciences and Technology, University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

ARTICLE INFO

Article history:
Received 19 April 2018
Revised 13 June 2018
Accepted 18 June 2018

Keywords:
Used cooking oils
Consumption
Production
Valorisation

ABSTRACT

The article quantifies, in a set of 23 countries, the amounts consumed of vegetable oils, the amounts of used oils produced after cooking, the amounts available for valorisation, and finally the quantities being valorised. The management practices adopted are also reviewed. Based on data collected, a *production factor, relating vegetable oil consumption with used cooking oil production,* of 0.32 is proposed. The valorisation factor, which quantifies the fraction of UCO being valorised, is higher in better performing countries (0.749) and worst in the remaining (0.232). Three consumption-valorisation factors, relating consumption with valorisation, were obtained: for high performing countries (0.274); intermediate performing (0.105); and under-performing (0.078). The management systems adopted by the different countries are based on either second-generation economic instruments (USA and Brazil), or on third-generation economic instruments (EU, Argentina, Japan). The former has allowed countries to attain better valorisation rates.

1. Introduction

The worldwide demand and consumption of vegetable oils have increased very rapidly throughout the last 15 years: from 83 million tonnes in 1999/2000 to 172 million tonnes in 2015/2016 (FAO, 2017a). Traditionally, these oils were used as food for humans, but the percentage used for other uses has been increasing over the last decade and a half: from 7.5% in 2000/2001 up to 34.7% in 2016/2017 (Gunstone, 2013). This alteration in the profile of vegetable oils use is with the consequence of environmental policies put in place to control greenhouse gases emissions (GHG), along with economic rationality, which has encouraged the use of biodiesel and ethanol, partially or totally, replacing petroleum-based fuels. Consequently, the growth rate in vegetable oils consumption has been larger than the growth of the world population (FAO, 2017a; TWB, 2017). This decoupling will continue over the next decade, starting only to reduce as the third- and fourth-generation biofuels progressively become more efficient and competitive.

Globally, the palm and soybean oils, with 38.4% and 34.6% of the market respectively, dominate the vegetable oils market (FAO, 2017a; Statista, 2018). The other vegetable oil fractions include sunflower (9.7%), rape (6.3%), peanut (4.1%), corn (2.1%), coconut (1.9%), olive (1.8%) and sesame (1.1%) (FAO, 2015a). Asia is the continent with the highest production of vegetable oils, with *ca.* 54% of the production, being Indonesia the world's greatest producer (~18% of total global production and 56% of palm oil production) (op. cit). China ranks second in the total world production, with about 14% in 2015, and is one of the largest producers of soybean and canola oils (IHS Markit, 2015). In EU-28, the estimated consumption volume of vegetable oil will decrease to 22.9 million tons by 2026. In 2015 this value was 24.0 million tons (Statista, 2018b). Greatly boosted by the biodiesel industry, soybean oil is extensively produced and used in the US, Brazil, Argentina and China.

The biodiesel industry in the United States of America (US) and European Union (EU) coupled with the rapid growth of the oil industry in Asia (particularly in Malaysia), has catapulted the consumption of vegetable oils (ICCT, 2013; Mittaine, 2016; Rosillo-Calle et al., 2009; Sani et al., 2013). Together, the EU, India, China and US consume more than half of world vegetable oil (Gunstone, 2013). However, the uses differ between regions. In EU, due to the use of rapeseed oil in biodiesel production, more than half of the consumption is for non-food purposes (although the situation varies widely from country to country). In the USA, the use for non-food purposes is much lower, being soybean oil the one with the highest weight in biodiesel production. In SE Asia, more than half of the oils are destined for industrial purposes, is

* Corresponding author.
E-mail address: lnunes@ualg.pt (L.M. Nunes).

https://doi.org/10.1016/j.wasman.2018.06.039
0956-053X/

responsible for the consumption of large quantities of palm oil (List, 2016). The non-food uses include the production of animal feed, soap, personal care products, biodiesel, paints, lubricants and greases. In countries where the biodiesel industry is more developed, the economic incentive for recovery is higher, with positive effects on the valorisation rates.

Used cooking oil (UCO) is a domestic waste consisting of vegetable oil that has been used in cooking or preparation food and is no longer suitable for human consumption (Gui et al., 2008; Kalam et al., 2011). So, incorrect disposal of UCO is an important environmental problem. If disposed into drains or sewers leads to blockages and odour or vermin problems, creates operation problems in wastewater treatment plants. They form products that linger in the environment for many years, polluting watercourses and soils causing severe negative impacts on ecosystems (EPA, 2000). The use of circular economy for UCO by enabling its recycling and reutilisation can help minimize technological and environmental impacts while contributing to economic efficiency.

Currently, there are several valorisation options for UCO. They include renewable energy/fuel use (Sidibé et al., 2010; Hellier et al., 2015; D'Alessandro et al., 2016), biodiesel and biogas production (Phan and Phan, 2008; Araújo et al., 2013; Talebian-Kiakalaieh et al., 2013; Zhang, et al., 2014a; Ortner et al., 2016; Miranda et al., 2018; Madheshiya and Vedrtnam, 2018), and other applications including lime mortars for restoration (Pahlavan et al., 2017), biohydrogen generation (Rodrigues et al., 2018), epoxidation waste vegetable oil as a primary plasticizer in poly(vinyl chloride) (PVC) films synthetic (Suzuki et al., 2018) and polihydroxyalkanoates production (Prasad and Sethi, 2013; Cruz et al., 2016).

The worldwide information about quantifies of UCO production and valorization, as well as the management practices adopted is very scarce and difficult to find. Much work has been done on the production of biodiesel from UCO using different pretreatments and treatments, and on the environmental impacts of those solutions. However, a systematic work that shows the management of UCO itself, including the quantities of UCO produced and the potential to valorize them hasn't yet been made. Thus, the objectives of this work are: (i) quantify the consumed quantities of vegetable oils, (ii) quantify the resultant amounts of used oils produced and the available for valorisation, and (iii) quantify the valorised quantities; and finally, (iv) identify the management practices adopted in the countries.

2. Methodology

2.1. 1. Quantification of cooking oil streams

The amount of used cooking oil produced during food preparation depends on the cooking procedure. Frying is the process where more used oil can be retrieved after cooking. In opposition, oils incorporated as ingredients in dishes will not result in usable wastes due to severe contamination. Therefore, of the total amount of vegetable oil consumption (TVOC) only a fraction results in the production of used cooking oil (UCO). The amounts actually collected and valorised are lower or equal to UCO, is here designated as valorised used cooking oils (VUCO). These are the three variables here analysed. The mathematical relationships between them are here given by Eqs. (1)–(3), where the non-dimensional parameters α, β and δ represent the *production factor*, *valorisation factor*, and *conversion factor* respectively. The latter is the product of the former two. The units of the variables are indicated as total mass per country per year, or after division by the population, as mass per capita per year. Volume-to-mass conversions were made when necessary using reference densities (Wiley-VCH Pub, 2003).

$$\textit{Production}: \quad \mathrm{UCO} = \alpha \mathrm{TVOC} \tag{1}$$

$$\textit{Valorisation}: \quad \mathrm{VUCO} = \beta \mathrm{UCO} \tag{2}$$

$$\textit{Consumption} - \textit{valorisation}: \quad \mathrm{VUCO} = (\alpha\beta)\mathrm{TVOC} = \delta \mathrm{TVOC} \tag{3}$$

2.2. Selection of the sample

Due to the difficulty in obtaining data for many of the countries, the research concentrated on the countries with Human Development Indices (HDI) (UNDP, 2016a) belonging to the very high human development class (HDI $\geq$ 0.800) (51 countries). Apart from these, China (HDI = 0.738), India (HDI = 0.624) and Brazil (HDI = 0.754) were included, due to their large population, and Bulgaria (HDI = 0.794) for belonging to the European Union (EU). An initial list of 54 countries has resulted (Fig. 1, Table S1 in Supplementary Material).

This methodology has the disadvantage of excluding Africa, Central America, part of Southern Asia, of Oceania, and of the Middle East. However, if the consumption of vegetable oil per country is considered (FAO, 2015a) and assuming that 71.3% of this amount is used in food preparation (Gunstone, 2013), the set of the countries here studied represents about 53% of the world population and 41% of the TVOC.

HDI index was selected because it considers a broad set of sociocultural factors beyond economic growth. The HDI can be used to assess national policy choices, making possible see how two countries with the same level of gross national income per capita can have different human development outcomes (UNDP, 2016a). Thus, the HDI is a summary measure of average achievement in three key dimensions of human development: to lead a long and healthy life, the ability to acquire knowledge, and the ability to achieve a decent standard of living (UNDP, 2016a). The HDI ranks countries into four classes: very high human development (with HDI values between 0.949 and 0.800), high human development (with HDI values between 0.796 and 0.701), medium human development (with HDI values between 0.699 and 0.550) and low human development (with HDI values between 0.541 and 0.352) (UNDP, 2016a).

The Gross domestic product (GDP) was used in the analysis since it is the most commonly used measure for the size of an economy. The GDP is the total of all value added created in an economy, i.e, the value of goods and services that have been produced, deduced by the imports (OECD, 2018). It does not reflect the sociocultural progress and well-being of a society (Ivković, 2016) and therefore is not well correlated with HDI, as shown also in our results.

2.3. Data collection and analysis

The following data were collected: Gross domestic product (GDP), HDI, TVOC, UCO (per sector of activity), national legislation related to waste management, in particular to UCO, and details about of the installed valorisation systems.

Data were retrieved from journal articles and grey literature, including reports and web-based documents. This method poses two major concerns: (i) the quality and detail of the information are not homogeneous; (ii) the methods used in the quantification of vegetable oils streams vary. Unfortunately, given the quite different level of development of valorisation systems installed in the different countries, along with the diversity of installed systems, such homogeneity and standardisation may be difficult to attain in the near future. The results here presented must be read at the light of such uncertainties. On our side, all was made to cross-validate every value with alternative sources, opting always for the most reliable one – i.e., the one that had undergone the best peer-reviewing process.