Renewable Energy 96 (2016) 33–41

Contents lists available at ScienceDirect

Renewable Energy

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

Technical and economical evaluation of olive mills solid waste pellets

Elias Christoforou, Angeliki Kylili, Paris A. Fokaides*

Frederick University, School of Engineering and Applied Sciences, 7, Frederickou Str., 1036 Nicosia, Cyprus

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form
20 February 2016
Accepted 19 April 2016
Available online 3 May 2016

Keywords:
Olive mills solid waste
Pellet plant
Pellets
Proximate and ultimate analysis
Supply chain
Life cycle costing

ABSTRACT

The low carbon- oriented strategy of the European Community has caused a radical progress in the exploitation of agricultural waste-derived biomass. Within the context of the food versus fuel debate, it seems that second generation biomass is gaining a lot of momentum. The aim of this study is to quantify the potential contribution of olive -oil solid waste pellets in the energy mix of an olive oil producing country – Cyprus as well as to examine its competitiveness against wood pellets. These research questions required a multidisciplinary approach, thus this work is conducted on two levels; the technical and the life cycle costing level. The technical analysis demonstrates the significant potential of olive mills solid waste in contributing in the country's energy mix, by taking into consideration both its proximate and ultimate analysis as well as its availability. The feasibility analysis presents the viability of olive mills solid waste pellets in Cyprus, and provides evidence for the olive mills solid waste pellets' competiveness over other commercially-available pellets. According to the findings of this study, pelletized olive mills solid waste pellets could enter the market with a selling price of less than 150 € tn^{-1} and could contribute in the households, industrial and agricultural sectors by 1114 toe, 934 toe, 835 toe, respectively.

1. Introduction

Olive mills solid waste is the solid residue of the olive oil production process. The current management practices of olive mills solid waste include its dumping in close proximity to the olive mills and deteriorating irreversibly in the environment, or utilising it in its raw form. Olive mills solid waste has been reported to have a high calorific value [1], and thus offers the possibility of its energy utilisation as a fuel for space heating purposes. The exploitation of waste for energy purposes can not only alleviate this common-among the olive oil-producing Mediterranean countries-problem, but also can contribute significantly to the fulfilment of the renewable energy generation targets of the Member States. With reference to the Directive 2009/28/EC [2] on renewable energy, the EU Member Stated have been called to achieve a 20% contribution from Renewable Energy Sources (RES) to their national energy mix by 2020. Member States are anticipated to encourage the promotion of biomass exploitation, as well as other RES through the identification and implementation of optimal actions and schemes in order to unravel their true potential and ensure the fulfilment of the national political obligations. The research question though set in the case of alternative raw material suitable for solid biofuels is to which extend these could cover the energy demand of a region, and whether their price is competitive to the available market available solid biofuels.

This study presents a multidisciplinary technical and costing analysis for the production of olive mills solid waste pellets for the case of Cyprus. In Section 2 the theoretical background of the olive mills solid waste production is presented, and the features of the energy system of Cyprus are introduced. Additionally, past works regarding the technical and economic feasibility of various agricultural residues-derived pellets are reviewed. The methodology followed for the feasibility analysis is analysed in Section 3. In Section 4 the results of the proximate and ultimate analysis of Cyprus olive mills solid waste are discussed. Also the potential of olive mills solid waste in Cyprus is justified in terms of a questionnaire survey among the olive oil mills' owners. Five case studies which take into account the potential penetration of olive mills solid waste pellets in the three main heating sectors (households, industrial and agricultural) are developed and discussed. Finally the life cycle costing of a pioneering pellet plant and its product (pellets) is presented. The study provides some significant conclusions regarding the significance of exploiting olive mills solid waste and its added environmental benefits, which are targeted towards the

* Corresponding author.
E-mail address: eng.fp@frederick.ac.cy (P.A. Fokaides).

http://dx.doi.org/10.1016/j.renene.2016.04.046
0960-1481/

scientific community and the decision-makers of the olive-oil producing regions.

2. Theoretical background

2.1. Olive mills solid waste

The olive tree (Olea europaea) is a species of small evergreen tree in the family Oleaceae, which is short and squat, and typically does not exceed 10 m in height [3]. Over 95% of the world's olive trees are found in the Mediterranean basin, due to environmental factors that make the soil and the climate ideal for their cultivation, flowering and production of their fruit [4]. Their fruit, olives, are small thinner-fleshed drupes, usually 2 cm long, and contain a seed commonly known as olive pit [3]. Olives are harvested in the autumn and winter and are processed for olive oil production. The olive oil industries of the Mediterranean countries are of great both agricultural and dietary importance-over 94% of the olive oil produced is actually consumed by the producing countries themselves [4].

Olive oil can be produced by employing olive presses or decanters, both of which also generate a solid waste, commonly referred to as olive mills solid waste. The hydraulic press represents the traditional method of separating the oil from the olive paste. By applying pressure on the olive paste, the separation of the liquid phase (oil and vegetable liquids) from the solid phase (olive mills solid waste) is achieved. The most modern technologies, the decanters, base their operation on the difference of the specific weight of the olive paste ingredients, so that the separation of the olive oil, water and solids is achieved through the aid of a rotating bowl. The addition of water in the three-phase decanter results in three products; olive oil, a larger quantity of vegetation water, and dry olive mills solid waste of 45–50% humidity. In the case of the two-phase centrifugal method where additional water is not required, the products are solely the olive oil and a semi-solid olive mills solid waste of about 55–70% humidity.

With biomass utilisation becoming a key priority within the European Community, a surge of researchers have become creative in exploiting various plant-derived biomass and quantifying their potential. An up-to- date review of the quantification practices for plant-derived biomass and a summary of their physical properties of plant-derived biomass applied for energy potential quantification are provided by Ref. [5]. Accordingly, olive mills solid waste has been indicated to contain a considerable amount of energy that can be released during combustion [6,7]. Its high calorific value, reported to be comparable to that of coal, offers the possibility of its energy utilisation as a fuel for space heating purposes. In Christoforou et al. [1], a novel approach based on Monte Carlo parametric modelling, for calculating the calorific value of biomass from measurements provided by elemental analysis, was presented.

2.2. Energy mix of Cyprus

For the case of Cyprus, the realization of the Directive 2009/28/EC on renewable energy [2] objectives is a challenge, due to the distinctiveness of its energy system. The Cyprus energy system operates in isolation and is not interconnected with other countries. Additionally, the lack of indigenous resources results in the country's heavy reliance on imported fossil fuels-leading to vulnerable, insecure and expensive energy. In fact, 92% of the electricity is generated by Heavy Fuel Oil (HFO), while the share of RES amounts only to the 1.2% [8,9]. In 2010 wind parks generated 33,286 MWh, biomass/biogas sources generated 24,802 MWh, and photovoltaics (PV) systems 4840 MWh [10]. In Refs. [11], a multi-criteria analysis (MCA) methodology was employed for the identification of the most optimal energy crops for their exploitation in Cyprus. Within the context of this work, the authors developed and introduced a fuzzy plant in their analysis, whose agronomic data reflected the characteristics of a second-generation energy crop. It was concluded that the promotion of second-generation biomass is more ideal, as well as more sustainable than the exploitation of any first-generation biomass. In view of these results, the olive mills solid waste can be considered as a good alternative for the country to increase the RES contribution in its energy mix.

In Cyprus, the olive mills solid waste is exclusively exploited for heat production in households, industry and agriculture. The industrial sector extends beyond the in-situ utilisation of the olive mills solid waste at the olive mills, where the raw material is generated to meet the demands for hot water, and at various other industries such as the cement industry. The cement industry in Cyprus is considered an energy intensive industry and utilizes a variety of alternative fuels including the olive mills solid waste in the production line. The utilisation of olive mills solid waste in the agricultural sector is observed in several farm units to meet the heating needs of greenhouses. As far as the power sector in Cyprus is concerned, there is no installed unit for the exploitation of olive mills solid waste. The electricity generated from biomass is mainly derived from farm animal waste from livestock facilities. In the transport sector, the use of biomass is mainly limited to the exploitation of cooking oil for biodiesel production, and there are no reports of olive mills solid waste utilisation as a raw material in the chemical process production of liquid biofuels.

2.3. Agricultural residues: technical and economic potential

The ongoing food versus fuel debate has given momentum and increased the interest of agricultural waste and residues' exploitation as biofuels for energy purposes [12]. Agricultural residue and waste have been reported to hold a better prospect to quantify potential in scenarios of an agriculture challenged to provide both food and fuel [13]. An extensive documentation of the practises for the quantification of the agricultural and crop, and forest residues potential has been conducted by Christoforou and Fokaides (2015) [5]. The main contributions of this work were the establishment of databases of typical properties of various types of plant-derived biomass and the delivery of a fundamental framework for the definition of the potential of biomass resources. Recent studies have estimated the availability of agricultural residues for bioenergy purposes to be 1500 PJ/yr on an EU- 27 level [14]. In Ref. [15] the energy contents of agricultural and forestry residues in Spain and the potential for the generation of electricity from them were assessed. The technical analysis indicated that the potential of the residues reaches 118 P J/yr, which in real terms can contribute by 11.25% to the country's total electricity generation. The results of the assessment of Lourinho and Brito (2014) [16] on the potential of agricultural and forest residues for Alto Alentejo, a region of Portugal are also very promising. It was estimated that their combined energy potential reaches the 158,000 GJ/year, an amount that can fully satisfy the electricity demand of three out of the nine municipalities investigated. Hiloidhari et al. (2014) [17] have also undertaken a large assessment of the potential of crop residues in the 28 states of India. Their analysis took into consideration a total of 39 residues from 26 crops, whose potential was estimated to reach 4.15 EJ, equivalent to 17% of India's total primary energy consumption. The residual biomass availability and energy potential for the case of a region in Argentina were estimated by Roberts et al. (2015) [18]. The analysis concluded that the availability of the agricultural and forestry residues biomass is 204,536 tn/yr, with 2605 TJ/yr of energy potential. The exploitation of this energy could