Biomass and Bioenergy 84 (2016) 107–117

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Environmental evaluation of biomass pelleting using life cycle assessment

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ARTICLE INFO

Article history:
Received 18 January 2015
Received in revised form
12 November 2015
Accepted 17 November 2015
Available online 7 December 2015

Keywords:
Life cycle assessment
Pellets
Non-linear programming
Olive husk

ABSTRACT

The exploitation of biomass for energy production purposes can significantly reduce the environmental burdens associated with the highly criticized fossil fuelled energy production. Life cycle assessment (LCA) methodology has proven to be one of the most effective tools for carrying out environmental impact analysis of any process or system. The interpretation of the findings of LCA can be used as a basis for recommendations and decision making in accordance to the goal and scope definition. The aim of this paper is to conduct a comprehensive LCA for the environmental evaluation of the biomass pelleting process with the focus being on the transportation and manufacturing stages. To achieve this aim, four scenarios are presented, investigating the pelleting process of olive husk, an abundant waste biomass found in Cyprus. Two alternative scenarios are developed in an effort to compare the centralised and the decentralised management of olive husk. Regarding those two scenarios, a novel mathematical parametric model was developed and Non-Linear Programming was applied for the computation of the optimal locations for a set of management facilities which achieve the lowest energy needs for transportation purposes. Additionally, a third and fourth scenario aimed to the comparison of the potential improvement of the environmental footprint of the olive husk pellets with regard to their reference cases (Scenario 1 and 2 respectively), when Renewable Energy Sources (RES) are incorporated in the pelleting process system. The authors concluded that the selection of location for the biomass management centres, as well as the employment of renewable energy technologies (RET) for energy generation can significantly affect the environmental impact of biomass utilisation. The environmental impact of olive husk pellet production was improved by more than 85% in selected impact categories when RES were incorporated in the manufacturing stage. The comparison of centralised and decentralised scenarios for olive husk management has indicated the latter to be the most environment-friendly solution.

1. Introduction

The exploitation of biomass for energy production purposes has gained a lot of popularity in the past years, as well as criticism. Nevertheless, scientific studies have been continually emerging providing evidence that a number of types of biomass have considerable amounts of energy potential [1–4]. At the same time, the careful biomass selection and the righteous biomass treatment are critical factors if biomass exploitation is to relief the natural environment from the conventional fossil fuelled energy production [5–7]. Pelleting is a well established process where milled fine particle biomass is compressed interfacially under high pressure for its densification. The process offers a number of benefits; it increases the energy density of the biofuel making its combustion more efficient, reduces the biofuel's handling, storage and transportation costs, and improves the overall biomass' quality, stability and durability [8]. The industry, the research community, and the decision makers have all been working together in making the biomass treatment processes as energy and cost efficient as possible. The industry has offered the technical know-how regarding the appropriate processes and machinery, the decision makers have already established standards for providing the markets with high quality products, and the scientific community has delivered a range of tools that effectively define the environmental impact of products and processes. Life cycle assessment (LCA) methodology has proven to be one of the most valuable tools for carrying out environmental impact analysis of any system or product. The interpretation of the findings of LCA can be used as a

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http://dx.doi.org/10.1016/j.biombioe.2015.11.018
0961-9534/

basis for recommendations and decision making in accordance to the goal and scope definition.

The aim of this paper is to conduct LCA for the investigation of the environmental impacts of the pelleting process using waste olive husk for the production of pellets for domestic heat purposes in Cyprus. For this purpose, four alternative scenarios have been developed, whose focus is on the generally accepted environmentally most harmful stages of the pelleting process; namely the biomass transportation and production stages. The investigated scenarios simulate a centralised and decentralized olive husk management centres, as well as the use of renewable energy instead of fossil fuels produced energy for both scenarios. For the definition of the pelleting centre location, a two stage approach was adopted. In the first stage the optimal location for a centralized and decentralized management centres were defined, using the non-linear programming. Based on the optimal locations, the exact energy required based on the actual road network of the country considered was calculated. This approach was found more comprehensive, instead of considering only the road network of a region, as in the latter case the optimal solution is restricted by the existing network, and does not allow the definition of the actually optimal position.

In Section 2 of the paper, a literature review is conducted regarding the pelleting process chain, the standardisation of pellet production, and the transportation of biomass. Past studies found in literature on the topic of LCA of pelleting processes are also reviewed. The methodology adopted for realising the LCA, as well as the novel methodology for computing the optimal locations for the olive husk management facilities are described in detail in Section 3. The LCA results of the four investigated scenarios are extensively discussed in Section 4. Finally, Section 5 presents some significant concluding remarks and suggests possible improvements for the optimisation of the overall process chain for the case of Cyprus.

2. Literature review

2.1. Pelleting process of olive husk

The pelleting process is based on a typical series of stages, which may vary depending on the condition of the raw material: reception of raw material; drying; grinding; conditioning; pelleting; cooling; screening; packaging. This series of processes is also applied for the production of the most common types of pellets (i.e. wood pellets) [9]. The raw material is primarily dried to reduce its moisture content to the appropriate levels, as defined in EN ISO 17225-6:2014 [10]. The moisture content of raw biomass was determined using the BM1-KIT Biomass Moisture Content Meter (Schaller GmbH).The raw biomass was then grinded to obtain uniform size particles with diameter no larger than the diameter of the pellet (~6 mm) [9].In some cases, the raw material may also be conditioned by influencing its moisture content, adding binders and additives, or preheating it through steam addition, in order to achieve optimal mechanical properties of the produced pellets, within the limits of the EN 17225 standards [11]. Binders have been proven to increase the strength and the durability of the pellets and enhance the overall quality of the pellet [12–17].The material is then forced through a pelleting press for its transformation into a pellet. The very high pressures and friction applied by the press, increase the temperature of the material so that lignin is soften and the material can be reshaped into the pellet form. The cooling and screening stage allows the formation of the bonds within the pellets and the separation of the loose material from the produced pellets [9]. Loose material is fed back into the system, while the produced pellets are packaged and ready to be stored or distributed to the market. Fig. 1 presents the entire process chains of biomass pelleting.

The fact that olive trees and their products constitute a large fraction of both the lifestyle and the economy of the Mediterranean countries of Eastern Europe, the sustainable exploitation of their solid waste for pellet production is a very active area of research. In fact, olive cake pellets are already produced on a commercial scale and marketed as a viable energy source in Europe [18]. The key objective of the work of Garcia-Maravera et al. [19] was the mechanical, physical and chemical characterisation of three different types of residual biomass derived from olive trees that were pelletized under different operating conditions, including initial moisture, diameter and compression length of the pellet mill die, and temperature of the pelleting process. Under this context, the optimal operational conditions for pellet production were defined. The results indicated that as a whole picture, the best pelleting conditions were low moisture content (9%), short compression lengths (20–24 mm) and temperatures higher than 40 °C. Similarly, Lajili et al. [20] investigated the thermal and physicochemical properties of pellets from olive mill by-products and sawdust blends. Among their analysis findings, it was also demonstrated that during the pelleting process of the specific agricultural wastes, the high value of moisture in olive waste decreases, while the ash content values of the pellets remained within the accepted national limits. The aim of the work in Miranda et al. [21] was the analysis of the energetic characteristics, densification properties and combustion behaviour in a pellet stove of different blends of two agricultural residues; dried olive pomace and pyrenean oak. Accordingly, the pelleting production process has been optimized for the densified final product to reflect the best characteristics. Additionally, Zamorano et al. [22] also analysed the physical and chemical characteristics of pellets derived from agricultural and forestry residues, including olive trees, produced in a pelleting plant. Their purposed was to identify the quality of the generated final products (pellets), which were produced at a privately owned industrial plant under the same manufacturing process conditions. In Brlek et al. [23], the quality of pellets made from different cultivars of olive cake with and without addition of binder and with or without conditioning of the raw material was investigated. For that reason, the quality of pellets in terms of their physical and chemical characteristics has been determined. The statistical analysis revealed that good physical and chemical characteristics of pellets can be obtained with conditioning at 50 °C, but also without conditioning, while the incorporation of binders in the pelleting process does not significantly affect the quality of pellets.

2.2. Standardisation of olive husk pellet production

The objective of the biomass related standards is to provide unambiguous and clear classification principles for solid biofuels and to serve as a tool to enable efficient trading of biofuels and to enable good understanding between seller and buyer as well as a tool for communication with equipment manufacturers [24].

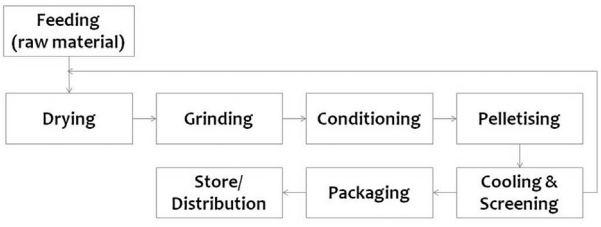

Fig. 1. Process chain of biomass pelleting.