Possibilities of Using By-Products and Residues of Avocado Tree for Energy Generation in Chania, Crete, Greece

John Vourdoubas

ABSTRACT

The use of renewable energies, including solid biomass, for energy generation is important in modern societies for coping with the current environmental challenges like climate change. The avocado-related biomass in Chania, Crete, Greece has been evaluated and its energy potential has been estimated. The reason of implementing the present study was the investigation of the possibilities of using the by-products and residues of the avocado tree in Chania for the production of valuable products and energy. Avocado’s fruit production in Crete is estimated at 6,300 tons annually while its by-products and residues have been evaluated at 550 dry tons annually. The avocado-related biomass in Chania is very low compared with the total biomass produced in Crete which is estimated in the range of 82,555 to 123,172 tons/year. Agriculture-related biomass in Crete is mainly produced from by-products and residues of olive trees, citrus trees, vineyard pruning and greenhouse wastes. The energy content of the avocado-related biomass in Chania has been estimated at 2.43 x 10^5 Kcal/year which is very low compared with the heat content of the total biomass production in the island. It is concluded that due to the low quantity of avocado by-products and residues produced in Chania, Crete the best options for their utilization are either their use for heat generation in rural areas or their disposal into the fields enriching the soil with nutrients.

Keywords: Agriculture, avocado, biomass, by-products, Chania-Crete-Greece, energy, heat content, residues.

I. INTRODUCTION

The necessity to promote climate change mitigation requires the gradual replacement of fossil fuels with renewable energies and low or zero carbon emission technologies. Biomass has been used so far worldwide for heat and electricity generation in many sectors with various technologies. Island of Crete, Greece has abundant agriculture-based biomass resources which are currently used for heat generation. The last few decades avocado trees have been cultivated in prefecture of Chania, Crete while the tree can produce significant quantities of biomass that can be used for energy generation or the production of several marketable products. Taking into account the fact that due to many reasons cultivation of avocado trees is expected to grow rapidly in Chania’s area it is interesting to investigate the energy potential of avocado-derived biomass in Chania, Crete and to compare it with the energy potential of other agriculture-based biomass resources in Crete. The current research is important since the evaluation of the potential of new biomass resources in Chania can facilitate their future utilization for energy generation replacing fossil fuels and helping the de-carbonization of the economy. Evaluation of the current avocado-derived biomass has not been reported so far in Crete and in Greece. Current European policies promoting circular economy favor the recycle and reuse of various by-products and wastes producing valuable products and energy instead of disposing them into the environment.

II. LITERATURE SURVEY

The literature survey is separated in two parts. The first is reviewing the published research concerning avocado by-products and residues and the second the research related with agricultural biomass resources in Crete.

A. Use of Avocado By-Products and Residues

Reference [1] has investigated the potential use of Avocado tree residues as energy source in rural communities. The authors stated that in Mexico over 150,000 ha are cultivated with avocado trees. They also mentioned that production of avocado pruning was in the range of 25.1 to 42.7 kg/tree annually (780-1,234 kg dry matter per ha annually) with energy potential in the range of 15.4 to 26.2 GJ/ha. Reference [2] has examined the use of biomass derived from avocado tree for the production of energy and bio-products. The authors stated that industrialization of the avocado tree cultivation has resulted in the production of large volume of wastes. They also mentioned that avocado-derived biomass can produce bio-energy, bio-fuels and other...
marketable products while two approaches can be used including either single processes or the bio-refinery concept. Reference [2] has studied the chemical composition of avocado-derived biomass. The authors stated that avocado kernel is rich in glucose while its peel is rich in lignin and in anti-oxidants. Reference [3] has studied the fuel properties of avocado stone. The authors stated that the global production of avocado fruit in 2014 was at 4,717,102 tons. They also mentioned that the higher heating value (HHV) and the lower heating value (LHV) of avocado stone were at 19.145 MJ/kg and 17.889 MJ/kg respectively, its oil content at 1.715 %, its ash content at 2.86% while its moisture content at 35.2 %. Reference [4] has studied the energy content of avocado residues. The authors mentioned that the fuel characteristics of avocado crop residues are very good. They also stated that avocado pruning has higher heating value than seeds while mixing cow manure with avocado wastes improves the quality of the final mixture. Reference [5] has studied the cultivation of avocado tree in Greece. The author mentioned that the production of avocado fruit in Greece in 2018 was at 6,633 tons/year while around 90% of it was produced in the prefecture of Chania, Crete. She also mentioned that the cultivated area in Chania was at 550 ha of arable land producing 6,300 tons/year while during 2017-2018 the annual fruit production was increased by 4.7%.

B. Agricultural Biomass Resources in Crete

Reference [6] has evaluated the biomass potential from agricultural wastes and its energetic content in Greece. They mentioned that Crete produces around 1,959,124 tons/year agricultural residues mainly consisted of olive pits and olive pruning. They also stated that the net calorific content of olive kernel wood is at 19.02 MJ/kg and of olive tree pruning at 14.85 MJ/kg. Reference [7] has estimated the biomass potential in Greece. The author stated that the annual quantity of olive tree pruning, in 2000, was at 995,324 tons while of olive kernel wood at 300,480 tons. Reference [8] has studied the use of solid biomass for heating residential buildings in Thessaloniki, Northern Greece mentioning that the total consumption of various types of solid biomass for heating buildings during the last years has been increased. Reference [9] has studied the energy exploitation of agricultural residues in Crete, Greece. The authors mentioned that the major agricultural residues in Crete are olive kernel, olive tree pruning, citrus pruning, vine residues, grape tree cuttings etc. They also stated that olive kernel wood and olive tree pruning were dominating in the production of agricultural residues and wastes in Crete. Reference [10] has investigated the possibility of using biomass residues in Heraklion, Crete for heat and power generation. They stated that in various existing studies the total biomass resources in Crete, including olive tree by-products and residues, vineyard pruning, grape pomace and greenhouse residues have been estimated in the range of 82,555 to 123,172 dry tons per year. They also mentioned that an 8 MWe power plant using solid biomass will be profitable if 40% of its capital cost is subsidized. Reference [11] has investigated the advantages of using solid biomass for heating buildings in Greece. The authors stated that biomass use is economically attractive while its burning results in higher CO₂ and SO₂ emissions. They also mentioned that primary energy consumption from biomass use is higher at 3-4% compared to diesel oil use. Reference [12] has studied the potential of biomass use in Canary Islands, Spain. The authors stated that biomass use in these islands is very low while the main renewable energies used are solar and wind energy. Reference [13] has investigated the current and future uses of biomass for energy generation in the island of Crete, Greece. The author stated that the main biomass uses in Crete are for heat production. Reference [13] has also investigated the use of heating greenhouses with renewable energies in Crete, Greece. The author stated that an agricultural greenhouse in Crete was using olive kernel wood for covering all its heating needs reducing significantly their CO₂ emissions. Reference [13] has studied the possibility of producing pellets from olive tree by-products and residues in Crete, Greece. The author mentioned that olive tree wood, olive tree pruning and olive kernel wood can be used under some conditions for pellets production in Crete. Reference [14] have investigated the biomass residues for energy production and habitat preservation in Portugal. The authors stated that biomass residues are used for space heating in various schools in Portugal. Reference [15] has investigated the energy potential of agricultural residues and livestock manure in Greece. The authors stated that the anaerobic digestion of these biomass resources can generate heat and electricity using the biogas produced. The generated energy corresponds at around 39% of the annual electricity consumption in the country. Reference [16] has investigated the integrated energy recovery scenarios of biomass residues in Crete, Greece. The author mentioned the synergies between energy generation and biomass waste utilization. He assessed several integration alternatives comprising anaerobic digestion and fuel cell use, anaerobic digestion and gas engines as well as biomass gasification and gas engines. Reference [17] has evaluated the use of wood residues in Crete as alternative fuels. The authors mentioned that olive and citrus tree pruning have been evaluated. They stated that during their burning the produced gases had low ash and sulphur content.

Aims of the current research are:

a) The estimation of the quantity and the energy content of the biomass related with avocado tree by-products, residues and wastes in Crete, and

b) The comparison of the quantity and the energy content of avocado-related biomass with the quantity and the energy content of other biomass resources in Crete.

After the literature survey the estimation of agricultural residues and by-products in Crete are presented followed by an estimation of avocado tree residues, by-products and wastes in Chania. After that comparison of energy content of avocado-related biomass with the energy content of other agriculture-related biomass resources in Crete is made followed by discussion of the findings, the conclusions drawn and citation of the references used.

III. USE OF AGRICULTURAL RESIDUES, WASTES AND BY-PRODUCTS IN CRETE

Agriculture was in the past the most important sector of Cretan economy while today it has been surpassed by tourism. Various crops and trees are currently cultivated producing several high-quality products that are famous in
Cretan diet while many of them are exported. Olive tree is broadly cultivated to day in Crete producing an excellent quality olive oil and the majority of agriculture-related biomass in the island. The main agricultural biomass resources produced are olive tree by-products and residues, vineyard pruning, citrus tree residues and greenhouse residues. Several biomass resources used for energy generation in Crete are presented in Table I. The annual biomass production of various trees cultivated in Crete is presented in Table II. The total biomass production from avocado tree in Chania, estimated at 550 dry tons/year in 2018, is very low corresponding at 0.45% to 0.67% of the total biomass production in Crete that is in the range of 82,555 dry tons/year to 123,172 dry tons/year [10]. Biomass related with various tree pruning in the island has been estimated at 118,894 tons/year [6]. Agricultural biomass in Crete is currently used for heat generation in residential and commercial buildings, in greenhouses and in various industries. Electricity generation from agricultural biomass has not been reported in Crete although organic wastes, landfills and the sludge from sewage treatment plants are used for biogas production and power generation. The energy content of various agricultural biomass sources in Crete has been estimated at 643,852 X 10^9 Kcal/year for olive kernel wood, 459,894 X 10^9 Kcal/year for vine-shoots, 8,385,867 X 10^9 Kcal/year for olive tree wood and pruning and 117,082 X 10^9 Kcal/year for citrus tree biomass [17]. The main abundant renewable energies in Crete are solar and wind energy, which are currently exploited commercially for heat and power generation. There are also abundant agriculture-related biomass resources that are already used, mainly for heat generation, while they could be further exploited in the future.

TABLE I: SEVERAL BIOMASS RESOURCES CURRENTLY USED FOR ENERGY GENERATION IN CRETE

| Biomass resource | Generated energy |
|------------------|------------------|
| Olive and citrus tree wood | Heat |
| Olive tree by-products and residues | Heat |
| Sludge produced in sewage treatment plants | Heat and power |
| Fried vegetable oils | Biofuels |
| Forest residues | Heat |
| Residues from various agricultural crops | Heat |

TABLE II: ANNUAL BIOMASS PRODUCTION OF VARIOUS TREES

| Crop          | Annual biomass production (kg/ha) | Annual biomass production (kg/tree) |
|---------------|-----------------------------------|------------------------------------|
| Avocado       | 780-1,324 (dry matter)            | 25.1-42.7                          |
| Citrus        | 1,360-3,516                       | 2.3-5.9                            |
| Orange        | 2,400-4,700                       | 4.1-9.4                            |
| Mandarin      | 3,330-4,050                       | 4.9-5.1                            |

IV. AVOCADO TREES IN CHANIA THEIR RESIDUES, BY-PRODUCTS AND WASTES

Cultivation of avocado tree in the prefecture of Chania, Crete, Greece is growing rapidly [5]. The local climate conditions are ideal for tree’s growth and the majority of the Greek avocado production, approximately 90%, is taking place in Chania’s area. Currently Greece is a minor producer compared with other countries in EU and worldwide. Avocado-related biomass includes tree pruning, leaves and kernels. Compared with other tree species the annual biomass production from avocado by-products and residues per tree is high while the productivity per ha is low (Table II). The energy content of avocado related biomass in Chania, at 2.43 X 10^9 Kcal/year (Table III), is very low compared with the energy content of several biomass resources produced in Crete [17]. The energy content of various avocado tree residues and wastes at 15.2 to 19.2 MJ/kg [3] (Table IV) is in the same range with the energy content of olive tree by-products and residues at 14.85-20.50 MJ/kg [6] (Table IV). Avocado-related biomass can be used for the production of various useful marketable products comprising oil, antioxidants and bio-fuels. However, the low quantities of avocado residues and wastes produced currently in Chania do not favor their further exploitation except their use as solid fuel for heat generation by burning. Currently many traditional agricultural crops like citrus trees and olive trees in Chania, Crete are not profitable compared with previous years. The farmers are trying to replace them with new and more profitable crops like avocado trees which are favored by the local climate conditions. Therefore, the prospects of increasing the cultivation of avocado trees in Chania, Crete replacing the old non-profitable crops are very promising. Considering a constant annual growth in fruit production at 4%, the production in 2028 will be at 9,326 tons compared to 6,300 tons in 2018. An attractive alternative for the energy utilization of avocado-related biomass in Chania is its mixing with biomass resources produced locally from other tree species and using the mixture as solid fuel. The characteristics of avocado production as well as the biomass produced from the tree in the prefecture of Chania, Crete, Greece in 2018 are presented in Table III while the heating content of avocado residues and other biomass resources in Table IV.

TABLE III: CHARACTERISTICS OF AVOCADO PRODUCTION AND THE BIOMASS PRODUCED FROM THE TREE IN PREFECTURE OF CHANIA, CRETE, GREECE (2018)

| Arable land | 550 ha |
|-------------|--------|
| Annual fruit production (2018) | 6,300 tons/year |
| Annual global avocado production (2014) | 4,717,102 tons/year |
| Annual production in 2028 assuming constant annual growth in fruit production at 4% | 9,326 tons/year |
| Annual increase in avocado production in Chania (2017/2018) | 4.7% |
| Annual biomass production | 1,000 kg dry matter/ha |
| Total annual avocado-related biomass production in Chania | 550 dry tons/year |
| Total annual production of biomass in Crete | 82,555-123,172 tons/year |
| Percentage of avocado-related biomass in Chania to the overall biomass production in Crete | 0.45%-0.67% |
| Higher heating value of avocado biomass | 4,421 Kcal/kg |
| Energy content of avocado derived biomass in Chania | 2.43 X 10^9 Kcal/year |
| Avocado production in Crete as percentage of the global production | 0.13% |
| Oil content in produced avocado in Chania | 1.715 % |
| Oil contained in the produced avocado in Chania | 108 tons/year |

TABLE IV: HEATING CONTENT OF AVOCADO RESIDUES AND OTHER BIOMASS RESOURCES

|          | HHV (MJ/kg) | LHV (MJ/kg) |
|----------|-------------|-------------|
| Avocado branches | 16.4 |          |
| Avocado leaves | 18.0 |          |
| Avocado peel | 18.7 |          |
| Avocado stone | 15.2-19.2 | 17.9 |
| Olive stone | 17.9-20.5 | 19.2 |
V. COMPARISON OF ENERGY CONTENT OF AVOCADO BY-PRODUCTS AND RESIDUES WITH THE ENERGY CONTENT OF OTHER AGRICULTURAL BIOMASS RESOURCES IN CHANIA

The quantity of solid biomass produced by avocado’s tree by-products and residues in the area of Chania, Crete, at 550 tons/year, is relatively small compared with the total, agriculture-related biomass in Crete, at 82,555 tons/year to 123,172 tons/year [10]. Its energy content at 2.43 x 10^9 Kcal/year has a small share in the total energy content of the biomass produced in Crete. Avocado-related biomass in Chania can be used for heat generation probably mixed with other types of solid biomass resources. Therefore, its use for energy production is not going to have major impacts in island’s energy balance. Agriculture-related solid biomass is already used in rural areas in Crete for heat production in greenhouses, small-size industries and in buildings. Therefore, avocado-related biomass can be also used in these heating applications, probably mixed with other biomass resources, instead of being disposed into the fields. The value of avocado-related biomass in Crete is low. Taking into account the current price of olive tree-related biomass in Crete and assuming the unit cost at 0.1 €/kg the value of 550 tons/year of avocado-related biomass in Chania’s area is evaluated at 55,000 €/year. However, taking into account that the prospects for higher cultivation of the avocado tree in Chania’s area are promising avocado-related biomass might have an increasing value in the future. Additionally, the possibility of producing several valuable and marketable products from avocado tree residues and by-products in Chania’s area cannot be ignored.

VI. DISCUSSION

Our results indicate that the annual avocado production in Chania, Crete represents a very small share of the global production. Studies regarding the characteristics of the avocado-related biomass in Crete have not been reported so far. However, published international studies have indicated that avocado related biomass contains many valuable and marketable products. Additionally, its energy content is attractive for its use for heat generation. Avocado-related biomass in Crete has a very small share in the total agriculture-related biomass production in the island. The low quantity produced annually in Crete does not allow its exploitation for the production of various valuable and marketable products. However, it can be used for heat generation in buildings and greenhouses preferably in rural areas. Mixing of avocado residues and by-products with other biomass resources like olive tree-derived biomass could facilitate its utilization for heating purposes. Our results also indicate that the current low production of avocado-related biomass in Chania, Crete will not have major impacts in energy production from renewable energy sources in Crete. They also indicate that the low quantity of by-products and residues of avocado tree produced in Chania, Crete do not offer any significant added economic value to the fruit produced.

VII. CONCLUSIONS

In the current work the quantities of avocado tree by-products and residues produced annually in Chania, Crete, Greece have been estimated as well as their energy content while they have been compared with the total agriculture-related biomass in Crete. Agriculture-related biomass in the island is mainly produced from olive trees, citrus trees, vineyard pruning and greenhouse residues. The annual avocado-related biomass in Chania, Crete has been estimated at 550 tons compared with the annual production of biomass in Crete at 82,555 to 123,172 tons. Similarly, the heat content of the avocado-related biomass in Chania, Crete, at 2.43 x 10^9 Kcal/year is very low compared with the heat content of the total biomass produced in the island. The energy content of several by-products and residues of the avocado tree is high at 15.2 to 19.2 MJ/kg being in the same range with the energy content of olive kernel wood at 17.9 to 20.5 MJ/kg. They can be used for heat generation, preferably in rural areas, with or without mixing with other biomass resources. Various marketable products can be recovered from avocado by-products and wastes. However, the low quantities produced annually in Chania do not favor their commercial exploitation. The present work indicates that due to the low quantities of avocado by-products and residues produced annually in Chania, Crete their commercial processing has limited interest regarding energy and economic benefits while the only viable options are either their use for heat generation or their disposal in the fields for enrichment of the soil with useful nutrients. Further work should be focused on the investigation of the possibility of mixing avocado-related biomass in Crete with other local biomass resources achieving higher heating values and probably producing pellets or briquets as standardized commercial green fuels.

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