A PRE-FEASIBILITY STUDY OF VINE SHOOTS AND GRAPE MARC BIOMASS SUITABILITY FOR SOLID BIOFUELS PRODUCTION

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Abstract. Grapes, one of the most cultivated fruits at global level represent, in the same time, a significant biomass source in the renewable energy production. The present review discusses conditions required for a pre-feasibility study for the vine waste biomass conversion to commercial densified biofuels. The purpose is to gather preliminary information in the scope of the energy production commercial applications of the vine wastes biomass.The vine shoots and grape marc biomass supply is approached from three perspectives: (1) economic performance of the biomass supply chain for higher productivity and cost effective operations; (2) technical performance of the biomass, with physical, chemical properties characterization; (3) environmental performance summary of the contaminants content. Results highlighted that biomass densification represents one of the most viable solutions for the energy production.

Keywords: biomass, sustainability, waste recovery, energy resources

INTRODUCTION

The wine industry represents one of the most developed agro economic sectors, grape crops (*Vitis vinifera* L.) being one of the world's largest and most important fruit crops. They are also considered a feedstock for renewable energy production, due to their richness in lignocellulosic compounds (Muhlack et al., 2017). In 2015, 3.2 million ha in the EU were cultivated with vines, Spain, France and Italybeing the main wine producing countries (74.1%), followed by Portugal, Romania, Greece and Germany (18.2%). Romania had one third of the 2.5 million agricultural vine cultivating holdings in 2015 (Eurostat, 2018).

In the wine sector the waste biomass produced during the technological processing consists of grape stalks, seeds, skin, pomace, known as grape marc, with numerous possible functions (Benetto et al., 2015; Galanakis, 2017), due to the antioxidants properties and richness in phenolic compounds (used in alcoholic fermentation) of the seeds and grape marc (Devesa-Rey et al., 2011) or due to the high amount of fermentable carbohydrates of the grape stems (Bayrak and Buyukkileci, 2018). The annual pruning of vineyards generates vine shoots, estimated between 1.5 – 2 tons per hectare (Spinelli et al., 2012). Vine shoots wastes are usually piled outside the vineyards, dumped, shredded, mulched or burned open-air on site for disposal, producing negative environmental impacts,such as particulate emissions in the atmosphere (Spinelli et al., 2014).

As the energy demand is rapidly increasing worldwide, due to the expanding world population, economic growth and industrial production, different types of renewable energy sources are required, fossil fuel reserves being slowly depleted(Zanetti et al., 2017; Muzikant et al., 2010; Pari et al., 2017; Saidur et al., 2011). Biomass represents a convenient energy source, its use for combustion and other purposes gaining more importance (Rentizelas et al, 2014; Manzone et al., 2016).

Before being used in domestic pellet stoves, vineyard residues have to comply with the new standards in force. Therefore, assessments of both the quality of biofuel and its combustion behaviour are necessary, by evaluating them according to the limit values for wood and non-woody pellets (Zanetti et al., 2017).

The purpose of this study is to gather the necessary information for a pre-feasibility study for the implementation of a conversion process from vine waste biomass to solid biofuels (densified biomass). A baseline discussion on the pre-feasibility of solid biofuels from vine shots and grape marc biomass is carried on in the following sections of the paper consideringthree perspectives: (1) economic performance of the supply chain for a higher productivity and cost effective operations; (2) technical performance of the biomass, with physical and chemical properties characterization; (3) environmental performance summary of the content of contaminants from fertilizers, heavy metals from soil, polluting emissions inventory and energy balance.

ECONOMIC PERFORMANCE OF THE BIOMASS SUPPLY CHAIN

A substantial recoverable amount of lignocellulosic material results from the annual pruning of vineyards. Disposing of the pruning wood entails a cost and the avoided cost of residues management plays a crucial role when the decision is made to harvest and process it into biomass fuel. Valorisation of pruned vine shoots can lead to sustainable development of rural areas(Thornley et al., 2008; Saidur et al., 2011).

On the other side, a rapidly growing demand shapes the global pellet market, though with a complex consumption dynamics and uncertainties of energy production, prices and biomass supply. The potential of the vineyard pruning residue for energy production is significant, since it presents values of moisture and calorific capacity in line with woodchips produced by short rotation coppice plantations. In addition, its characteristics have a limited variation in time or with the vine varieties. In contrast, biomass supply is sensitive to vine culture varieties and can vary from year to year. Moreover, available biomass amount estimates are uncertain since a grape/biomass ratio correlation with the weather conditions cannot be rigorously established (Manzone et al. 2016).

The viability of recovering vineyard pruning depends on how the residue costs are managed, as well as on how the value added is redistributed between owners, harvesting contractors and biomass users. The vineyard pruning residue biomass recovery is a complex chain of logistics, involving transport, storage, handling and pre-treatment, with constraints on the controllability of the operational parameters, costs, energy and emissions during biomass processing. These parameters depend on factors such as: the amount of pruning potentially available; harvesting techniques; the location of the energy plants; the pre-treatment; the energy conversion process and the equipment involved; the transport routes, fuel consumptions and truck operations(Rentizelas et al., 2009; Saidur et al., 2011).

An optimal harvesting, transport and storage process secures the profitability of pruning recovery and use. Specific transport energy and greenhouse gas (GHG) emissions are higher when less dense materials are transported. Density can be increased by using square bales, although the baling equipment is more expensive. According to Cavalaglio et al. (2017), transportation influences the most the biochip cost (about 60% of total production cost). It is clearly suggested that, storage costs can be reduced if unsheltered infrastructures are used, which could in turn cause energy losses and higher costs.

Vine shoots generate a considerable amount of waste material: Mendivil et al. (2013) reported an average 2.5 tons per hectare, while Spinelli et al. (2012) reported 2 fresh tons or 1.13 oven-dry tons per hectare on a seasonal basis. The costs of recovering pruned vine shoots varies between 121 and 193 euro, as pointed by Mendivil et al. (2013), being estimated for the whole process of recovering including chopping, collection, and transportation of prune vine shoots to a storage (1-4 km), and considering the depreciation costs associated with the machinery used.Moreover, Mendivil et al. (2013) explains the process of storing and naturally drying the vine shoots in roofed sheds, not be necessarily enclosed. This process represents aneconomic solution for the biomass supply, the cost per hectare being 25 euros for the case when the staked biomass density is 198 kg/m3 and no more than 20% moisture in 3 months. This process leads to a cost of about 70 euros per ton. Therefore, due to additional conditioning and transport costs, pruned vine shoots are not a competitive biomass for power plants located away from the vineyard, but it can cover the heating and electricity needs at the vineyard. Under these circumstances, a viable commercial alternative could be the biomass densification.

According to Toscano et al. (2013), Italy produces 21 Tg of dry matter per year from residues resulting from agriculture, forestry and agri-food industry. In the wine industry, the annual production is around 0.5 Tg dry matter, the largest amount resulting from grape marc (60%).The potential of the residual biomass from a hectare of grapevine was evaluated to about 19 GJ of gross energy.

TECHNICAL PERFORMANCE OF THE BIOMASS

Vine shoots (pruning residues). Vineyard biomass waste is more appropriate for a conversion to fuel for generating heat and electricity on a small scale, either to supply the vineyard exploitation needs or to be forwarded to proximity plants. Technically, feeding wood chip boilers with pruning waste is compatible, since mixing forestry wood chip with pruning waste increases biomass fluency, though the heating value of vineyard pruning residues is slightly lower. Despite the high energy potential for heat generation, the high moisture content requires extra energy and personal input for drying. Moisture content is a critical issue during the biomass storage step, causing a reduction of combustion temperatures. Mendivil et al. (2013) reported that the pruning residues moisture content varies between 52% and 55%, typical for the woody biomass. The ash content of a solid biofuel determines which combustion process and flue gas treatment is most suitable. While tree wood biomass have ash contents <0.3%, Rioja vine shoots have ash contents of up to 3% of their dry-basis weight (Mendivil et al., 2013).

A comparative study realized by Manzone et al. (2016) between several vine varieties over a reference period of 15 years, reflects minor variances of the biomass characteristics, exception for the pruning residues production which, for an average plants density of 4000 plants per hectare, ranged from 1850 kg ha^{-1} to 5360 kg ha^{-1} of fresh matter (per plant productivity varied from 0.45 kg to 1.34 kg). The higher heating value averaged 17.98 MJ kg^{-1} and the lower calorific value averaged 7.66 MJ kg^{-1}, with an average ash content of 3.85%. Moisture content during harvesting, for the different vine varieties and for the whole period, was around 50%, with no differences, while values for the feedstock tree species reach 60% in the poplar wood and 45% in the black locust wood.

The higher heating value of vineyard pruning residuesobtained by Spinelli et al. (2012) was 18.7 MJ kg^{-1}, a good result compared to that of forest trees, ranging from 19.4MJ kg^{-1}for broadleaved trees to 20.2 MJ kg^{-1} for conifers, due to their high resin content. They found the average moisture content of vine shoots ranging between 40% and 45%.

Grape marc. The high energetic value of grape marc can be confirmed by calorimetric measurements of the combustion temperatures and high heat values. Various studies found gross calorific values ranging between 18 MJ kg^{-1} and 19 MJ kg^{-1} for vine prunings, and 20.39 MJ kg^{-1} in the case of grape seeds (Brunerova et al., 2017; Gravalos et al., 2016; Nasser et al., 2014).

Brunerova et al. (2017) analysed the grape marc suitability for energetic usage. The moisture content was measured after drying and it was found suitable for briquette production. Their test results showed gross calorific value 19.17 MJ kg^{-1}, net calorific value 17.94 MJ kg^{-1}, moisture content 6.43%, ash content 6.6%, volatile matter content 86%, mechanical durability 28.3 ± 3.5%, rupture force 19.11± 6.3 N mm^{-1}, volume density 1183 ± 48.5 kg m^{-3}. The value of the ash content was higher, but still comparable to other fruit waste biomass, like dates (2.65%) or jatropha press–cake (4.36%) and the difference was even more substantial compared to wood biomass (0.5-3%). Briquette samples mechanical tests showed low levels of rupture force and mechanical durability, despite a high volumetric density. They observed a level of mechanical durability (DU) of 28%, meaning a low level of the briquette mechanical quality, since the commercial product DU should be > 90%, while high quality briquette biofuels must achieve DU >95% according to the standard EN ISO 17831–2:2015 (Brunerova et al., 2017).

Burg et al. (2017) focused on the quality of the pellets produced from grape marc and used three input materials: grape marc (humidity 10 %), grape cane (humidity 11%), and hay (humidity 15%), mixing them together at different percentages of grape marc.In order to qualify the grape marc usage for energy purposes and for pellet production,they performed determinations of mechanical ruggedness, apparent density, combustion heat and calorific value for the pellets. Their results indicated that the heating power varied between 16.07 and 21.14 MJ kg^{-1}, with the highest heating power values for the seeds and grape marc in original state, which is related to the oil component in grapevine seeds. Their results suggest the possibility of the usage of grape marc mixtures with other materials (hay, grape cane) for the production of pellets.

Toscano et al. (2013) detailed the composition of grape marc through an exhaustive battery of tests for the physical-chemical characterization of grape biomass types (marc, stalks, grape skins, grape seeds, grape seed oil, oilcake, extraction meal) using standard methods. They blended grape marc for energy applications with other biomass of higher quality, like wood chips, to improve energy properties while reducing ash content. They found that chlorine and sulphur concentrations were similar for all components, higher than for wood chips, sulphur in particular, but significantly lower than for wheat straw. Chlorine and sulphur, in combination with potassium, lead to corrosion mechanisms, requiring the use of special materials for boiler, heat exchanger system and coating tubes.

ENVIRONMENTAL PERFORMANCE OF THE BIOMASS

Vine shoots (pruning residues). The analyses on pruning wood conducted by Duca et al. (2016) confirmed the presence of pesticide residues and heavy metals, even if in a very low content, copper and zinc being particularly used in vineyards These metals, subject to bio-accumulation, last in pruning residues, but also penetrate in the soil. Vine pruning biomass contamination with pesticides residues, in particular copper, can also occur by mixing it with soil during the collection operations with harvesting machines.The application of pesticides does not cause significant contamination with chemicals, since these are almost completely weathered prior to the biomass harvesting. Moreover, Duca et al. (2016) showed copper concentrations ranging from 8.5 mg kg^{-1} to 19.2 mg kg^{-1}, and zinc concentrations ranging from 9.9 mg kg^{-1} to 15.5 mg kg^{-1}, depending on the product used for the vine plant treatment. Unlike the small scale domestic boilers, large scale power plants with emission filters could cope with industrial chips copper concentrations up to 226 mg kg^{-1}.

For the conventional vineyards, the amounts of the pesticides detected in the biomass were largely under the Italian legal thresholds. Moreover among the 15 chemicals, azoxystrobin, dithiocarbamate, folpet, sulphur and boscalid, were almost completely weathered, while others were more persistent (Spinelli et al., 2012).

Silvestri et al. (2011) also isolated traces of pesticides: sulphur and copper for organic farming biomass wastes, but also low traces of applications (sulphur, ciprodinil, fluodioxonil, mepanipirim, boscalide and dimetomorf) against the oidium, grape mildew, and botrytis, in the conventional vineyards pruning residues.

According to Pizzi et al. (2018), combustion emissions in open field can exceed 120 times for the CO, and 30 times for the total suspended particles the level observed in a pellet boiler. Moreover, compared to wood pellets, the vineyard pruning residue pellets reveal that their higher N content causes higher NO_x, occurring at a combustion temperature <1300°C and suggest to blend the two biomass types in order to reduce N, but also K and other inorganic elements forming total suspended particles dust emissions. Also, the higher the heat power is, the lower are the CO emissions. Pizzi et al. (2018) also pointed out that, since the oxygen needs show the same air excess ratio (1.7 to 2) for both types of biomass combustion, a boiler can be fed with either vine pruning residue or wood pellets of the appropriate size.

According to Mendivil et al. (2013) a solution to minimize the costs and CO_2 emissions could be to use or process further the biomass on site. An energy input estimate for the grinding and densification processes is of 313 kWh per dry basis ton.

Grape marc. According to Toscano et al. (2013), among the grape marc components, seeds are the best fuel with a higher level of heating value, due to their oil content, and a lower level of the ash content. Moreover, globally, heavy metals concentrations are lower in the grape marc than in wood chip levels, except for copper and nitrogen is 4-5 times greater. The organic vineyards exposure to the bio-pesticides applications increases the copper concentration in the grape marc fractions, in particular in skins, causing fly ash pollution (volatile ash at combustion), altogether with potassium, sulfur and chlorine. Thus, emission prevention systems can be installed, like activated carbon sorption systems for SOx, HCl and polychlorinated dibenzodioxins or reduction zone for nitrogen (Toscano et al., 2013).

An energy producing processes comparison conducted by Zhang et al. (2017)proves that the grape marc combustion GHG releases are significantly greater than in the cases of the pyrolysis and composting, but combustion and pyrolysis generate more energy for less overall waste. Zhang et al. (2017) explains that the emissions can be controlled by using vine residues blends with wood, by improving the combustion chamber insulating capacity or by using filters. It is clearly suggested that environmental pollution is significantly inferior by boiler combustion than by open field combustion.

CONCLUSIONS

Considerable quantities of vine wastes are generated during the processes of vine cultivation (vine pruning) and wine production (grape marc). Current management practices (disposal, open field combustion, mulching and composting) are not an option anymore, on the long term, in the recent environmental regulatory framework and under the economic constraints. The market demand and the exploitations energy needs create the opportunity to recycle the residues into solid fuels, at low cost and with relatively reasonable capital investments.

Based upon the above discussed perspectives one can conclude that biomass densification represents one of the most viable solutions for the energy production. Studies proved that the available technology already used for wood biomass processing combustion can be adapted with minimal changes in order to be compatible with the alternative biomass characteristics. Although researches indicate that using pesticides, in the conventionally managed vines, do not have a significant negative effect on the harvested biomass, the main issues related to the vine and wine residues remain their exposure to phyto-sanitary treatments, their incomplete or inefficient combustion (due to their hard ash in a high content), and their compatibility with the new commercial pellets standard ISO 17225, due to their CO, NO_x and PM>10 (flying ash) emissions, to their copper concentrations and to their week mechanical performance.

The most appropriate use of the vineyard biomass waste as solid biofuel is for combustion heat and electricity generation on a small scale, which can be further usedfor processing at the vineyard or to be supplied to neighbouring plants. Pure grapevine fruit waste biomass, although not suitable for briquette production, is suitable for combustion purposes due to the high energy potential and chemical composition. Technically, vine pruning and grapes marc are compatible for feeding wood chip boilers, since mixing forestry wood chip with pruning waste increases biomass fluency. Large industrial applications are also suitable for pellets produced from mixtures of vine residues with woodas they dispose of emissions mitigation and combustion improvement technologies.

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REFERENCES

1. Bayrak, E., Buyukkileci, A. O. (2018). Utilization of white grape pomace for lactic acid production. GIDA Journal of Food, 43, 129-138.
2. Benetto, E., Jury, C., Kneip, G., Vazquez-Rowe, I., Huck, V., Minette F. (2015). Life cycle assessment of heat production from grape marc pellets. Journal of Cleaner Production, 87, 149-158.
3. Brunerova, A., Brozek, M. (2017). Is it advantageous to reuse fruit waste biomass from processing of grapevine (*Vitis Vinifera L.*) for briquette production?. Proceedings of International Conference “Engineering for Rural Development”, Jelgava, 555-560

4. Burg, P., Masan, V., Ludin, D. (2017). Possibilities of using grape marc for making fuel pellets. Proceedings of International Conference “Engineering for Rural Development”, Jelgava, 1333-1338
5. Cavalaglio, G., Cotana, S. (2007). Recovery of vineyards pruning residues in an agro-energetic chain. 15th European Biomass Conference and Exhibition, Berlin, 1631-1636.
6. Devesa-Rey, R., Vecino, X., Varela-Alende, J.L., Barral, M.T., Cruz, J.M., Moldes, A.B. (2011). Valorization of winery waste vs. the costs of not recycling. Waste Management, 31, 2327-2335.
7. Duca, D., Toscano, G., Pizzi, A., Rossini, G., Fabrizi, S., Lucesoli, G., Servili, A., Mancini, V., Romanazzi, G., Mengarelli, C. (2016). Evaluation of the characteristics of vineyard pruning residues for energy applications: effect of different copper-based treatments. Journal of Agricultural Engineering, 497, 23-27.
8. EN ISO 17831–2:2015Solid biofuels - Determination of mechanical durability of pellets and briquettes - Part 2: Briquettes.
9. Eurostat (2018).Vineyards in the EU – statistics, Eurostat Statistics Explained, July 31, 2018. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Vineyards_in_the_EU_-_statistics/ Accessed 11.10.18.
10. Fereshteh Mafakheri, Fuzhan Nasiri (2014). Modeling of biomass-to-energy supply chain operations: Applications, challenges and research directions. Energy Policy, 67, 116–126.
11. Galanakis, C.M. (2017). Handbook of Grape Processing By-Products: Sustainable Solutions. (1th ed.). London, Academic Press.
12. Gravalos, I., Xyradakis, P., Kateris, D., Gialamas, T., Bartzialis, D., Giannoulis, K. (2016). An Experimental Determination of Gross Calorific Value of Different Agroforestry Species and Bio-Based Industry Residues. Natural Resources, 7, 57-68.
13. Manzone, M., Paravidino, E., Bonifacino, G., Balsari, P. (2016). Biomass availability and quality produced by vineyard management during a period of 15 years. Renewable Energy, 99, 465-471.
14. Mendivil, M.A., Munoz, P., Morales, M.P., Juarez, M.C., Garcia-Escudero, E. (2013). Chemical characterization of pruned vine shoots from La Rioja (Spain) for obtaining solid bio-fuels. Journal of Renewable and Sustainable Energy, 5, 033113-1 – 033113-12
15. Muhlack, R.A., Potumarthi, R., Jeffery, D.W. (2018). Sustainable wineries through waste valorization: A review of grape marc utilization for value-added products. Waste Management, 72, 99-118.
16. Muzikant M., Havrland B., Hutla P., Vechetová S.(2010).Properties of heat briquettes produced from vine cane waste – Case study Republic of Moldova. Agricultura Tropica Et Subtropica. 43 (4), 277-284
17. Nasser, R.A., Salem, M.Z.M., Al-Mefarrej, H.A., Abdel-Aal, M.A., Soliman, S.S. (2014). Fuel characteristics of vine prunings (Vitis vinifera L.) as a potential source for energy production. BioResources, 9, 482-496.
18. Pari L., Suardi A., Santangelo E., García-Galindo D., Scarfone A., Alfano V. (2017). Current and innovative technologies for pruning harvesting: A review. Biomass and Bioenergy,107, 398-410.
19. Pizzi, A., Foppa Pedretti, E., Duca, D., Rossini, G., Mengarelli, C., Ilari, A., Mancini, M., Toscano, G. (2018). Emissions of heating appliances fuelled with agropellet produced from vine pruning residues and environmental aspects. Renewable Energy, 121, 513-520.
20. Rentizelas Athanasios A., Tolis Athanasios J., Ilias P. Tatsiopoulos (2009). Logistics issues of biomass: The storage problem and the multi-biomass supply chain. Renewable and Sustainable Energy Reviews, 13, 887–894.
21. SaidurR., AbdelazizE.A., DemirbasA., HossainM.S., Mekhilef S. (2011). A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews, 15,2262–2289.
22. Silvestri, S., Cristoforetti, A., Mescalchin, E., Spinelli, R. (2011). Recovery of pruning waste for energy use: agronomic, economic and ecological aspects. The Central European Biomass Conference, Graz-Austria, January 26-29.

23. Spinelli, R., Nati, C., Pari, L., Mescalchin, E., Magagnotti, N. (2012). Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues. Applied Energy, 89, 374–379.
24. Spinelli, R., Lombardinia, C., Parib, L., Sadauskiene, L. (2014). An alternative to field burning of pruning residues in mountain vineyards. Ecological Engineering, 70, 2012-2016.
25. Thornley P., Rogers J., Huang Y. (2008). Quantification of employment from biomass power plants. Renewable Energy, 33, 1922–1927.
26. Toscano, G., Riva, G., Duca, D., Foppa Pedretti, E., Corinaldesi, F., Rossini, G. (2013). Analysis of the characteristics of the residues of the wine production chain finalized to their industrial and energy recovery. Biomass and bioenergy, 55, 260-267.
27. Zanetti, M., Brandelet, B., Marini, D., Sgarbossa, A., Giorio, C., Badocco, D., Tapparo, A., Grigolato, S., Rogaume, C., Rogaume, Y., Cavalli, R. (2017).Vineyard pruning residues pellets for use in domestic appliances: a quality assessment according to the EN ISO 17225. Journal of Agricultural Engineering, 612, 99-108.
28. Zhang Nansen, Hoadley Andrew, Patel Jim, Lim Seng, Li Chao'en (2017). Sustainable options for the utilization of solid residues from wine production. Waste Management, 60, 173-183