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THE MORE WINE, THE MORE GAS? ESTIMATION OF THE BIOENERGY POTENTIAL OF WINERY WASTEWATER IN MOLDOVA: CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT

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Abstract. Wine is one of the most ancient commodities in the world. The critical residues from the wine industry are grape leaves, stems, grape pomace, grape seeds, yeast lees, tartrate, and wastewater. The indiscriminate disposal of produced wastewater has adverse environmental and health consequences. Nevertheless, winery effluent has substantial prospects as an energy source. Hence, this paper aims to briefly showcase the potential of energy generation from wastewater in the wine industry through anaerobic digestion. From literature and statistical records, in 2018, the cultivation of grapes in Moldova covered about 126,873 ha of land and produced 730,171 t of grapes, with over 24% pressed for wine production. Consequently, the industry released over 6 billion litres of wastewater. Therefore, by anaerobic digestion of this effluent, there is a potential for the wine industry to produce 459,166 MWh of electricity annually to satisfy nearly 287,000 people. This potential represents a very important step towards energy self-sufficiency of the wine industry and a contribution to the sustainable development goals concerning wastewater, energy and sanitation.

Key words: Biofuel; Biogas; Cleaner production; Sustainable development; Waste valorisation.

Реферат. Вино является одним из древнейших товаров потребления в мире. Важнейшими остаточными продуктами винодельческой промышленности являются виноградные листья, гребни виноградной грозди, виноградные выжимки, виноградные косточки, дрожжевой осадок, тартраты и сточные воды. Неизбирательная утилизация образующихся сточных вод приводит к неблагоприятным последствиям для окружающей среды и здоровья. Однако сточные воды виноделия имеют существенные перспективы в качестве источника энергии. Поэтому, данное исследование направлено на то, чтобы вкратце продемонстрировать потенциал производства энергии из сточных вод в винодельческой промышленности посредством процесса метанового брожения. Согласно данным из литературы и статистическим данным, в 2018 году выращивание винограда в Молдове занимало около 126 873 га земли и было собрано 730 171 тонн винограда, более 24% которого было использовано для производства вина. Следовательно, в результате деятельности винодельческой промышленности образовалось более 6 миллиардов литров сточных вод. Таким образом, при помощи метанового брожения сточных вод винодельческая промышленность может производить 459 166 МВт/ч электроэнергии ежегодно, чтобы удовлетворить потребности в энергии почти 287 000 человек. Это демонстрирует шаг к достижению энергетической самообеспеченности винодельческой промышленности и вклад в достижение целей устойчивого развития, направленных на проблемы сточных вод, энергии и санитарии.

Key words: Биотопливо; Биогаз; Чистое производство; Устойчивое развитие; Валоризация отходов.

INTRODUCTION

With the tremendous development and ensuing quest for sustainability around the globe, circular economy has become a mantra. Recycling, minimisation, avoidance of waste, and responsible consumption are all springing from the Sustainable Development Goals of the United Nations (UN). Industries are charged by environmentalists and concerned entities to consciously implement strategies to mitigate pollution and reduce water and carbon footprint (UN, 2015). In the developed countries, the emission levels from the industrial sector have been under a high degree of monitoring and control, thus, showing diminishing trends. However, the reverse is the case in the developing world. The industrial output ratio of emissions per capita is about 1:12 (Cherniwchan, J. 2012). In Moldova, industrial growth is also evident. The number of industrial enterprises increased from 428 to 5,089 between 1995 and 2013 (Ciobanu, M. 2015).

The wine industry's value chain from the vineyard to the wine press generates various by-products, including wastewater. The total grape production for wine globally in 2018 was over 29 million t FAO (2021). One tonne of grape pressed for wine production and 1 m^3 of wine produced emit, on average, 3.5 m^3 and 2.86 m^3 wastewater, respectively (Bolzonella, D. et al., 2019). Therefore, the global wine industry discharged over 101.5 million m^3 of wastewater. Although the wine industry is not regarded as a major pollution source, the effluent has a high organic load, acidic pH, varying salinity and nutrient concentration which suggests that the wastewater is prone to cause danger to the receiving environment (Mosse, K.P. et al., 2011). Specific mechanisms are used to treat effluent from wineries to mitigate environmental pollution. These approaches include electrochemical oxidation, Fenton's oxidation, photo-Fenton, ozonation, photolysis/photocatalysis (Amor, C. et al. 2019), constructed wetlands (Flores, L. et al. 2019), lagoons, bioreactors, activated sludge, ion exchange and reverse osmosis (Mosse KPM et al., 2011). Likewise, several of these treatment processes have advanced, incorporating the recovery of resources. Consequently, tartaric and malic acids (Mosse, K.P. et al. 2011), phenolic antioxidants (Cañadas, R. et al. 2021), and biogas (Gaspar, M.C. et al. 2019; Pachón, E.R. et al. 2020) have been recovered from the treatment of winery effluent.

Pollutants present in wastewater can be eliminated through the process of anaerobic digestion. Other possibilities during this process include pathogenic destruction, solid content reduction, odour removal, and the consequent production of biogas which can be recovered for cleaner energy production. Moreover, for optimum operation and increased biogas generation, the nature of the substrate plays a significant role. The pH of the process is controlled to about 6.5 to 7.5, high organic matter content is measurable in the Biochemical oxygen demand value, while and the biodegradability of the substrate is critical. Another crucial parameter is the carbon to nitrogen ratio with an optimum value of 25:1 and 35:1 for mesophilic and thermophilic digesters, respectively. Furthermore, the digester operating conditions to be controlled include the hydraulic retention time, organic loading rate, total solid content and temperature. The extent of removal of pathogens, organic matter, pollutants and solid content represents an indicator of the efficiency of the anaerobic digestion process (Meegoda, J.N. et al. 2018; Gaspar, M.C. et al. 2019).

However, the Moldovan state is troubled with limited energy availability. Over 70% of the electricity supply in Moldova is imported from countries like Ukraine. The energy sector is a top priority as the government seeks diversity in the energy mix. With the influx of more renewable energy sources, biofuels remain one of the leading subsectors (ITA, 2021). Thus, the valorisation of agricultural residues and agricultural waste is a viable option.

Moreover, Moldova's annual final energy consumption between 2015-2019 increased from 101,231 TJ to 112,157 TJ. In 2019, such sources as coal, heat, electricity, natural gas, biofuels and waste and oil products contributed by 4, 7, 12, 18, 23, and 36%, respectively, to the final energy consumption (NBC, 2020). Biofuel and waste remain the second most significant contributor (NBC, 2020), and the government plans further to explore this energy source (ITA, 2021). Therefore, the winery industry in Moldova offers such an opportunity. Its value chain needs to be developed and expanded to include options for processing by-products and waste materials for beneficial use (Duca, G., Mereuta, A 2017), in this case, waste to energy purposes.

Since the Moldovan state is a major wine producer and consequently releases these effluents in large volumes, this study attempts to estimate the energy potential of the effluents from the wine industry and its estimated value using the biomethane derived mainly from the anaerobic digestion process. The present study demonstrates the viability of biogas as an energy source in the winery industry of Moldova.

MATERIALS AND METHODS

This study used secondary data sources such as scientific literature indexed on the Web of Science, Scopus and Google Scholar. Data and overviews from FAO and the UN were also used. These resources described the location and mapping out of the current situation and possible valorisation of wastewater from the wine industry in Moldova. Also, insights were drawn from meetings and conversations with local authorities and visits to various wineries within the Czech-UNDP partnership for SDGs cooperation project *Turning wine waste into profit: possibilities of the Moldovan wine industry* in collaboration with Alliance for Energy Efficiency and Renewables (AEER). Parameters estimating the energy potential of winery wastewater were calculated as follows:

The Chemical oxygen demand (COD) load, according to E. Nikolaidou et al. (2016) is given by:

$$COD\ yield\ (kg\ COD) = COD\ (kg/m^3)\ \times\ Vol.\ of\ wastewater\ (m^3) \quad (1)$$

The methane (CH_4) yield is estimated using the method of G. Buitrón et al. (2019):

$$Methane\ yield\ (m^3) = COD\ yield\ (kg\ COD)\ \times\ 0.35\ m^3/kg\ COD \quad (2)$$

According to E. Nikolaidou et al. (2016), electricity generation in a biogas engine is given by:

$$\text{Electricity (kWh)} = \text{Vol. of methane } (m^3) \times 3.5\ kWh/m^3 \qquad (3)$$

RESULTS AND DISCUSSIONS

Waste generated by the wine production

Winemaking involves several stages, from grape harvesting to wine bottling. Several by-products, including wastewater, are generated during this processing stages. After grape harvest, the stems are removed, and the grapes are pressed to obtain the juice. The juice is subjected to fermentation at a (controlled temperature. For red wine, the red grapes pomace is present during the whole process, which permits the colour and tannins in the skin to be taken up by the juice. The pomace is separated from the wine after the fermentation process. For white wine, the juice of the white or red grape is fermented in the absence of the pomace. The sediments at the bottom of the fermentation vessel, called the lees, are removed after fermentation. The lees contain yeast and other solid by-products. After fermentation, the wine rests and is further fermented for a more extended period, producing more sediments. The wine is then stored in oak barrels or bottles, labelled and sold depending on the final product (Johansson, M. 2012). D. Bolzonella et al. (2019) and E.R. Pachón et al. (2020) explained in more details the process of wine production and the waste materials generated. The primary waste materials are grape leaves, stems, grape pomace, grape seeds, yeast lees, tartrate and wastewater. A summary of these is presented in Figure 1. It can be concluded that the winemaking stages that yield effluent include stemming and crushing, pressing, fermentation, clarification, storing, filtration and bottling.

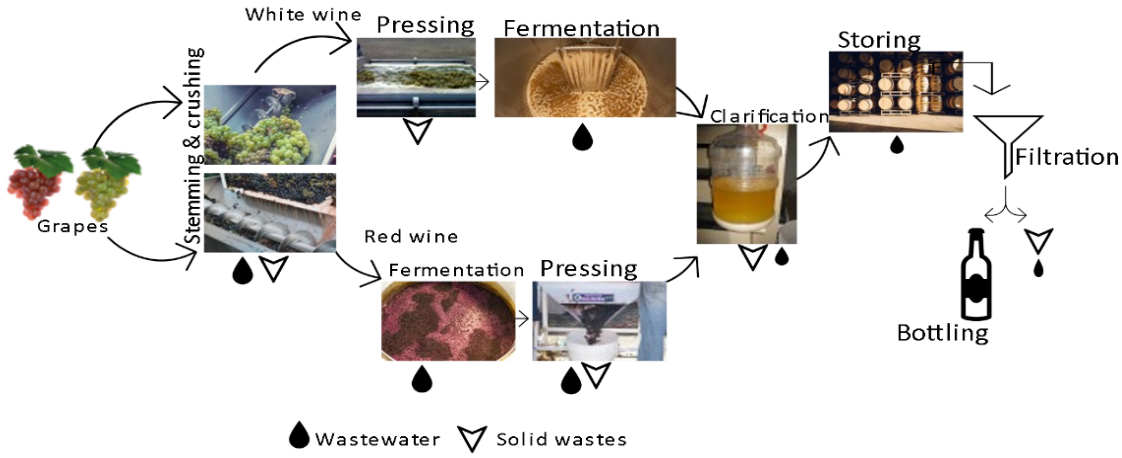

Figure 1. *Flowchart of waste generation in a typical wine production process (based on D. Bolzonella et al. (2019)).*

Furthermore, wastewater production during winemaking stems from different sources such as cleaning operations (e.g., floors and equipment), leakages, laboratory effluent and stormwater channelled into the wastewater management system). Moreover, the volume and quality of the effluent depend on the working period and the processing technologies. Winery wastewater (WWW) is produced in the pre-vintage, early, peak, post, and non-vintage times (Ioannou, L.A. 2013). Wineries generate 1.3-1.5 kg of residues per litre of wine, and 75% is wastewater (LA Ioannou, 2013). The proportion of wastewater emitted per litre of produced wine amounts to 2.86 litres (Bolzonella, D. et al. 2019).

Wastewater generated in wine production

The wastewater generated in the Moldovan wine industry in 2018 can be estimated using the grape tonnage for wine produced. For every tonne of grape pressed, 3-4 m^3 of wastewater is generated (Bolzonella D. et al., 2019). Hence, in 2018 the wastewater released by the wine industry in Moldova was in the range of 5-7 million m^3. The outcome for other years is shown in Figure 2. According to OIV (2021), the downward trend in wine production in Moldova in recent years could be assigned to the current process of revamping and renovation of its grapevines.

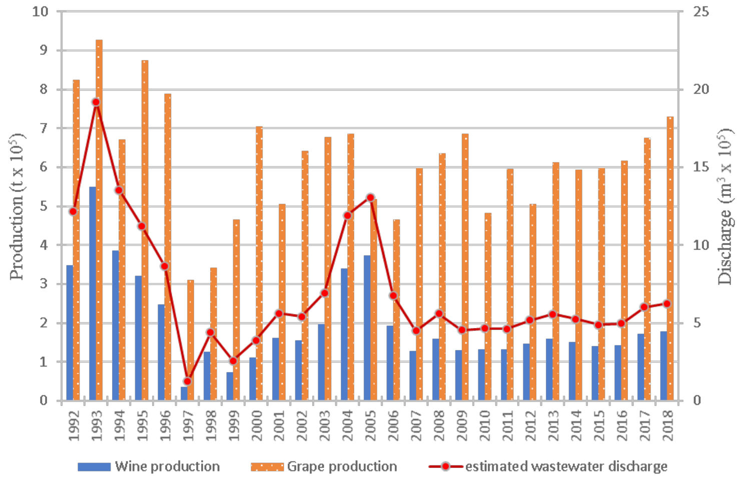

Figure 2. *Production of grape, quantity of processed as wine, and calculated wastewater discharge during wine production in the priod 1992-2018 in the Republic of Moldova (based on FAO (2021)).*

Energy potential of vinery wastewater

The winery wastewater treatment by different processes has been previously studied. However, anaerobic digestion is the most suitable treatment process for energy production. Previous studies have characterised WWW from various wineries and seasons for treatment purposes and bioenergy evaluation. For the development of a chemical precipitation technique for the removal of organic pollutants and phenols (Luz, S. et al. 2021), the viability of treating highly concentrated WWW effluent and biogas production (Buitrón, G. et al. 2019), analysis of biogas potential (Gaspar, M.C. et al. 2019), thermal and photo degradation of organic pollutants (Amor C. et al., 2019). Details of WWW characteristics from these studies are summarized in Table 1.

WWW has been deemed suitable for anaerobic digestion; however, the quantity of biogas produced was improved by co-digestion with other winery waste, animal manure and crop residues. On the other hand, the treated wastewater often does not meet stringent discharge standards. Nevertheless, G. Buitrón et al. (2019) studied a treatment process that increased both the methane production volume and the pollutant removal rate. Table 1 shows the composition of WWW from various studies, which hints at its suitability for energy production.

Table 1. *Composition of winery wastewater*

Cellulose (%wt., d.b.)	Hemicellulose (%wt., d.b.)	Lignin (%wt., d.b.)	COD (g/L)	BOD (g/L)	VS (g/L)	pH	Reference
-	-	-	3.225	1.266	-	4.26	S. Luz et al. (2021)
-	-	-	220.8	-	129.6	3.49	G. Buitrón et al. (2019)
4.4	1.3	4.8	-	-	-	-	MC Gaspar et al. (2019)
-	-	-	0.60	0.145	-	4.37	C. Amor et al. (2019)
-	-	-	15.53	8.858	7.98	5.0	KPM. Mosse et al. (2011)

BOD- Biochemical oxygen demand; VS- Volatile solids.

Biomethane potential

Depending on the bioreactor design, organic loading rate, and influent concentration during anaerobic digestion, the specific methane production from WWW varies significantly. Various studies report 400-600 litres per kg of COD removed (Moletta, R. 2005), or 1-5.5 (mean 2.6) m^3 CH_4/m^3/day (Buitrón, G. et al. 2019), while the pollutant removal ranges between 90-95% (Moletta, 2005) or up to 97% (Buitrón, G. et al. 2019). The methane content is mainly about 60-70% of biogas produced (Moletta, R. 2005). Table 2 shows the annual production of energy from WWW in Moldova. It was generated using the quantity of wine produced by each selected winery assuming 75 cl/bottle of wine. At a rate of 2.86 m^3 of wastewater per m^3 of wine produced, the annual wastewater discharge was calculated for each winery.

Then, the COD load was calculated using equation (1) and from Table 1 mean COD of 0.60 g/L. The Acroex wine holding has the highest potential of about 8 GWh, though it is not necessarily the biggest wine producer in Moldova. Since the electricity consumption per capita per year in Moldova is 1,600 kWh (IEA, 2021), the energy from Acroex and LionGri combined can provide the electricity needs for 22.5% of the inhabitants of Cahul city, where they grow their vines.

Consequently, based on Figure 2, the entire wine industry in Moldova generates of wastewater annually, resulting to 374,829,000 kg COD, yields 131,190,150 of biomethane equivalent to 459,165,525 kWh of electricity. Hence, the entire industry generates enough electricity for 286,978 people annually.

Table 2. *Energy potential of WWW in selected wineries in Moldova per year*

Winery	Production* (bottles)	Wine production (m3)	Estimated waste-water discharge (m3)	Biomethane potential (m3)	Electricity potential (kWh)
Acroex Wine Holding	50,000,000	37,500	107,250	2,252,250	7,882,875
Vinaria Bostavan	36,000,000	27,000	77,220	1,621,620	5,675,670
LionGri	18,000,000	13,500	38,610	810,810	2,837,835
Chateau Vartely	13,500,000	10,125	28,957.5	608,107.5	2,128,376

*Values based on AWH (2005); Bostavan (2019); Château Vartely (2017); LionGri (2021)

CONCLUSIONS

This study aimed to quantify the energy potential of the winery wastewater discharged in Moldova. Data about the quantity of wine produced combined with equations for COD load, methane yield and generation of electricity from biogas engine were used to calculate the annual volume of wastewater generation and the electricity generation rate of wine industry. A case study of four wineries showed a combined annual electricity potential of 18,524 MWh from the anaerobic digestion of wastewater. On the other hand, the entire wine industry annually emits about 6,247,150 m3 of wastewater which could potentially generate an estimated 459,166 MWh of electricity. The energy potential of this waste stream can meet the annual energy needs of over 286,000 people. This potential energy can be used for heating, lighting, laundry and other residential activities. Based on the findings of this study, future research should be directed towards testing and optimising different small-scale biogas technologies in wineries, mainly in the remote parts of Moldova, since effluent parameters and operating conditions vary from one winery to another. Hence, the harmful environmental impacts of winery wastewater are mitigated while providing energy for economic benefits.

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