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Energy Consumption and CO_2 Emissions Related to Wine Production: The Case Study of a Winery in Douro Wine Region-Portugal

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Abstract: Water use and its associated energy consumption in wine processes are often unnoticed in best practice. Many proprietors are insensitive to how water is used within their winery procedures. Key areas of environmental concern currently faced by the wine industry include water and energy use and the production of greenhouse effect gas emissions, among others. This review revealed that the practice within wine organizations tends to be largely unexplored and inadequate. To address the present needs for accurate water and energy resources control, it is vital to develop research on how water and energy are related and used in wine production to increase the effective use of these resources, minimizing the related environmental impact. The main aim of this paper was to find the relationship between energy and water utilization and subsequent CO_2 emissions from a winery located in the Douro Valley, contributing to its sustainability in terms of resources consumption. A two-year monitoring plan on water use was implemented, and the related energy consumption and CO_2 emissions were calculated. The results showed high values of energy (148.5 kWh/day) as well as related CO_2 emissions (54 kg CO_2/day) associated with high water consumption (that ranged from 16.20 to 27.66 m^3 water/day). This information is very important and contributes to enlarging the database of environmental parameters related to wine production in the Douro wine region, creating opportunities for environmental improvement.

Keywords: winery; Douro Wine Region; water; energy; CO_2 emissions

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1. Introduction

Given the socio-economical importance of the wine industry in Portugal and the rest of the global wine areas where vitiviniculture is a major activity [1,2], and considering the existing necessity for accurate water and energy resources management, it is imperative to develop research concerning how water and associated energy are used in wine production to increase the effective use of these resources. At each step of the winemaking process, water is always required, from crushing and pressing grapes over fermentation and aging to the end product. Water is also at the core of the cleaning and disinfecting system, ensuring that wine-making areas, tanks, barrels, and the bottling line are properly cleaned [3].

Due to its international scale, wine production environmental issues, among all the water and energy use, have gone largely unmapped. Water use and its associated energy consumption in wine processes are often unnoticed in best practices, with many proprietors being insensible about how water is used [4,5]. However, wine companies are currently adopting more sustainable beliefs and shifting their practices to attain sustainability goals (namely "Goal 6–Ensure availability and sustainable management of water and sanitation for all" and "Goal 12- Ensure sustainable consumption and production patterns"), increasing their social responsibility and increasing the value of their wines simultaneously.

Freshwater scarcity is an imperative issue on the environmental agenda, being increasingly considered in different sectors [6], while the water footprint (WF) is quickly gaining worldwide recognition [7]. There are some interesting studies about water footprint assessment in the wine industry.

Herath et al. studying New Zealand's wines, assessed the WFs of a wine bottle using diverse methods [8] and assessed the impact of water use through the life cycle of grape-wine production on water resources [9]. Ene et al. [10] carried out a water footprint calculation of a bottle of wine produced in a medium-size wine production plant in Romania.

Due to its importance in economic production and the world distribution market, wine is one of the most analyzed products. Literature studies highlighted matters such as glass bottle production, energy consumption, and the final distribution [7,11–19]. Other publications analyzed conceptual and methodological aspects [20,21], focused on the wine chain [22,23].

Nowadays, the wine industry is under an increasing legislative burden to be more efficient and sustainable and has started to adopt integrative protective methods instead of the old-style reparatory environmental practices [24]. Therefore, there is rising attention within the wine industry on highlighting its input to sustainable development. Several regulation documents from national or international entities working in the wine sector were published [25–27], and also several programs and frameworks to assist winemakers were made, for example [25]: the Code of Sustainable Winegrowing Practices Workbook as the basis for the Sustainable Winegrowing Program [28], the "Commitment to Sustainable Development" [29], the "Vignerons en Développement Durable" [30], the "Entwine," the Australian Environmental Protection System [31], the Certified Sustainable Wine of Chile [32], and in Portugal, in 2016, the Alentejo wine production region developed a set of rules to support the production and promotion of more sustainable wine [33].

According to some authors, an appropriate evaluation of the sustainability of a product or process has to adopt a Life Cycle Thinking (LCT) perspective, considering all the life cycle steps involved [25,34–37]. Petti et al. [38] conducted ample scrutiny of LCA studies in the wine area to determine imperative operational aspects related to goal and scope, system boundary, data quality and availability, multi-functionality concerns, inventory tools and impact assessment approaches, as well as results and research findings. These authors emphasized the key points in the methodology and administration of the wine supply sequence and processes, highlighting the assets and missing items and providing valuable insights and pertinent endorsements for both LCA analysts and winemakers.

The main concerns in vinification are electric energy use in equipment; production of solids during the process, which may be reused in other sectors; wastewater generation due to cleaning and some leakage that may occur during the process; CO_2 emissions (about 80 kg/t grapes) and volatile organic compounds (0.93 kg/t grapes) during the fermentation [39], apart from the CO_2 associated with the energy to water use. The major sectors/processes that use water are the fermentation tanks, cask washing, vat sopping, bottling lines, cellars, and the crush pad. Water use and disposal require pumping and other processes, raising energy costs [40].

Christ and Burritt [41] have performed a state of the art review to examine the key areas of environmental concern presently handled by societies in the global wine trade. Among others, water and energy use and the production of greenhouse gas emissions were some of the most relevant environmental factors. According to the authors, practice within wine associations tends to be largely unexplored and inadequate, reflecting the absence of quantitative and qualitative environmental data required to bring environmental improvement.

In Portugal, few works have been done:

- Some of them mainly focused on the determination of the water footprint of a wine bottle [42,43];
- Sustainability evaluation of Portuguese wines [25];
- LCA considering freshwater use in the wine industry [44];
- Water to wine production [2].

The setup that delivers water for several uses needs clean water treatment and supply systems that consume energy, mainly for pumping and subsequent treatment and distribution. Water preservation is consequently directly related to energy preservation [45].

Regarding the present necessity for accurate water and energy management, it is essential to investigate how the water and energy nexus is considered in wine production to increase the efficient use of these resources, minimizing the related environmental impact. This paper aims to understand the energy used for water utilization and the related CO_2 emissions from a medium-sized winery in the Douro Valley to propose some efficient measures and contribute to the winery's sustainability in terms of resource consumption. The paper is divided into several sections. In Section 2, the methods used and the case study are described, then Section 3 discusses the results and the study's main findings. In Section 4, some conclusions and further ideas for future works are presented.

2. Methods

2.1. Energy to Water in Pumping Operation

Electrical energy (kWh) is consumed when a unit volume (m^3) of water is pumped. Reardon and Newell [46] highlight that there is a linear relationship between the energy spent for groundwater pumping and the depth from which it is pumped at a specific pressure.

The energy consumed for pumping well water depends on the location of the water source relative to the release site and the frictional resistance to flow [47]. It also depends on the pump efficiency, pipeline length, diameter and roughness, and volumetric demand for water.

Table 1 presents some referenced values for energy to water pumping.

Table 1. Energy to Water referenced values.

Where	Energy Consumption	Reference
California	0.14–0.69 kWh/m^3	[48]
Canada	0.25–3.02 kWh/m^3	[49,50]
Canada	Flow rate of 100–950 m^3/d consumed 0.84–3.02 kw h/m^3 Flow rate of 1000–10,000 m^3/d consumed 0.25–1.11 kw h/m^3	[50]

2.2. Energy to Water in Clean Water Treatment Processes

Groundwater pushed from underground aquifers generally needs basic disinfection with the help of simple technologies (filtration, chlorination, ozonation, or ultraviolet irradiation). Normally, a groundwater treatment plant may have a pumping system, a filtration system, a storage tank, a disinfection tank, and a support distribution pump [45]. Most of the groundwater treatment in the north of Portugal depends on the aquifer's quantity, quality, and contamination. Most of them are composed of a filtration unit (normally a sand composed filter), a storage tank, and a disinfection process.

Filtration is very important as it clears the water, helping to remove the major of the coarse impurities, including the major suspended solids. The energy requirements for these gravity filters are in the range of 0.005–0.014 kW h/m^3 [45].

According to Arpke, & Hutzler, Ref. [51] groundwater chlorination consumes 0.002 kWh/m^3.

2.3. Energy to Water in Wastewater Treatment Processes

Generally, wastewater is treated following three degrees of treatment: primary, secondary, and sometimes tertiary.

Primary treatment is typical among different WWTP, and the different phases within the treatment have diverse energy consumption. Screening and inorganic suspended solids removal processes need low energy intensity, while primary sludge pumping is the process within the primary treatment that consumes more energy. According to Kenway et al. [52], in Australia, the total energy requirements for the primary treatment varies between 0.01 and 0.37 kWh/m^3.

For the second stage of treatment, there is a wide range of options, most commonly the activated sludge treatment process. However, this choice widely influences the energy intensity values required for this treatment. Different values of energy consumption are pointed out in different countries. The mean electrical energy consumption for the secondary stage of treatment may vary between 0.2 and 1.89 kWh/m^3 in the USA [53,54], while in Sweden, this value extends to 0.42 kWh/m^3 [55] per example.

The energy intake during the tertiary treatment depends on the level of treatment required, depending on the quality of the discharge effluent required, according to the point of discharge referred to in national/local legislation. The state-of-the-art review discloses that tertiary treatment is the stage where energy consumption is higher. The total energy consumption required for the advanced tertiary treatment ranges between 0.23 and 10.55 kWh/m^3 in Australia [56]. In New Zealand, these values are lower, varying between 0.32 and 0.88 kWh/m^3 [57,58]

2.4. CO_2 Related Emissions

CO_2 production depends on the total energy intake, so different values are presented for several countries [58]. The procedures and backup tools adopted to estimate CO_2 emissions are "made-to-order" with respect to direct needs [59,60]. According to Rothausen and Conway, [61] in South Africa, 112 kg CO_2/m^3 are emitted in the wastewater treatment, while in California, the value for recycled water is 1.023 kg CO_2/m^3, and in Canada (Toronto), 117.31 g CO_2/m^3 are emitted in the water-treatment facility [58]. In Portugal, 369.23 g of CO_2 is emitted per kWh of electricity consumed [62]. This value is an outcome of the mixed technologies used in Portugal to produce electrical power: renewable energy (hydroelectric, wind power, solar power, among others) and non-renewable electric energy (petrol/gas-based).

2.5. Study Area

The study area (Lower Corgo) is part of the Alto Douro Wine Region, designated as a World Heritage by UNESCO as a Living Cultural Landscape [Figure 1].

The vinification center studied is a modern medium-sized winery that employs around twelve employees (Winery B from [2]).

This winery uses water exclusively from a private well that is filtered and treated locally.

In Figure 2, it is possible to observe the operations where water and energy are interrelated in the winery. Energy use is inherent to water use; however, this is directly related to the amount of water pumped since no energy is used to produce hot water used in the process.

2.6. Data Collection

Data were collected from bibliographic sources (when they were not available/trustworthy in the case study), and others were collected in the winery.

Water consumption was collected by the authors in the winery daily for two years using common water metering and register devices (Winery B [2]). The energy consumption was estimated considering the range of values obtained through the bibliographic review. As said before, this winery uses water exclusively from a private well, so the extraction of water from underground aquifers primarily requires energy for pumping. Then the water is treated with a filtration and sometimes with a disinfection process. After use, the wastewater produced is gravitationally conduced to a wastewater treatment plant that performs the primary and secondary treatment. It is then discharged into a municipal wastewater network for final treatment in the municipal wastewater treatment plant.

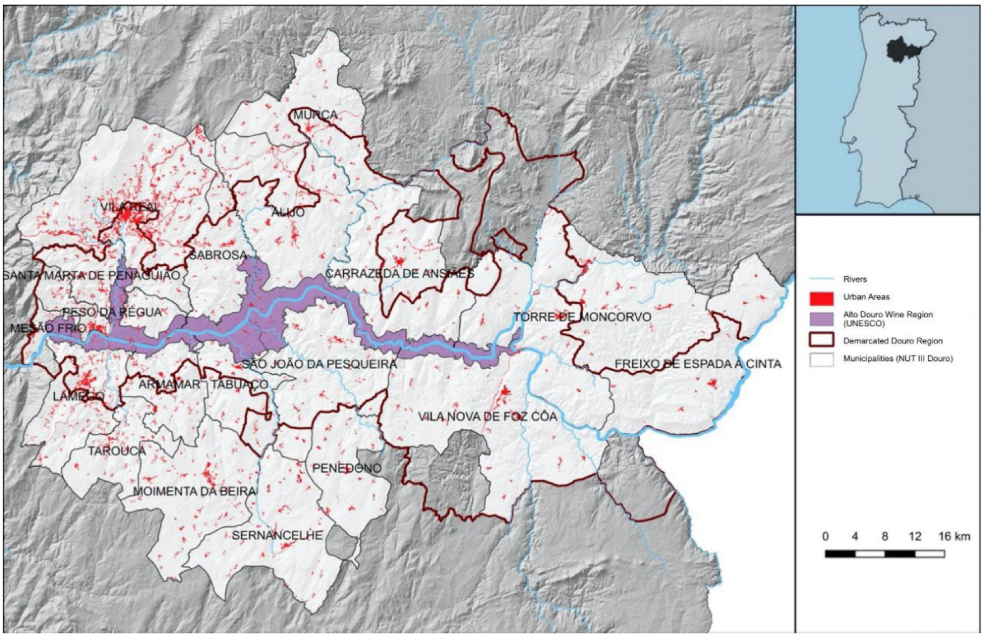

Figure 1. Alto Douro Wine Region [2].

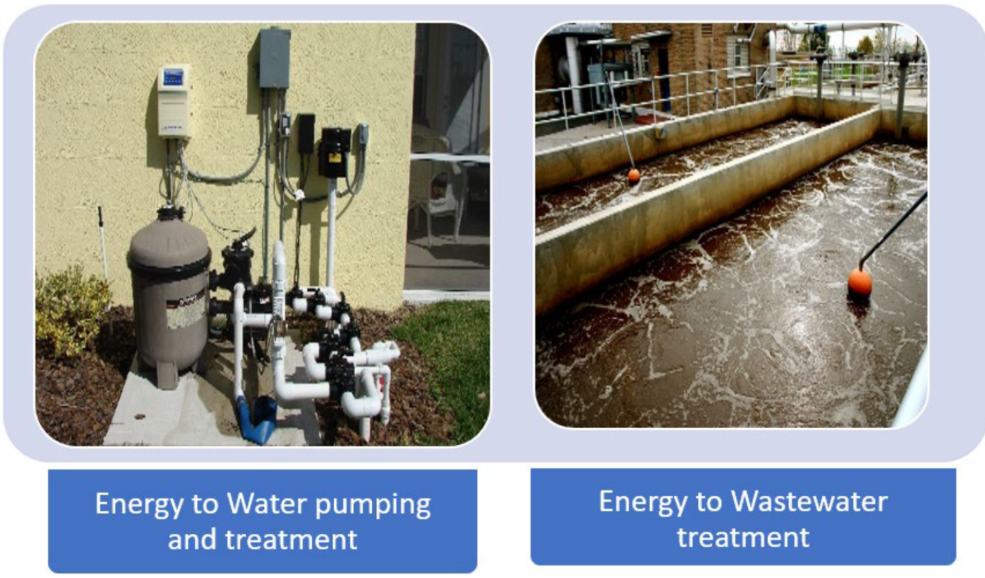

Figure 2. Energy to water relations scheme in the winery (the images are not from the winery in question).

The contribution for CO_2 emissions was obtained using the conversion factors referred to before (369.23 g of CO_2 emitted per kWh of electricity consumed as referred by Silva-Afonso et al. [62].

A previous paper published by the authors presented the water used in the winery (Table 2). Two years of monitoring were performed, and there was a considerable difference between the water consumption in the first and the second year. These differences were correlated with the different volumes of wine production within these years, according to the irregularity in grape production over different years due to normal variations in climatic and agronomic conditions.

Table 2. Average water consumption in the winery (Data from [2]).

	m^3 Water/Day
1st year	27.66
2nd year	16.20

3. Results and Discussion

Given the values presented in the bibliography and considering the minimum and maximum values presented in Table 2, energy consumption was calculated in relation to water use within the winery (Figures 3 and 4). As shown, pumping and secondary wastewater treatment are the most important operations related to energy consumption. Secondary wastewater treatment may consume more than 50 kWh/day, and pumping operations use more than 80 kWh/day, considering the maximum values referred to in the bibliography (Figure 4).

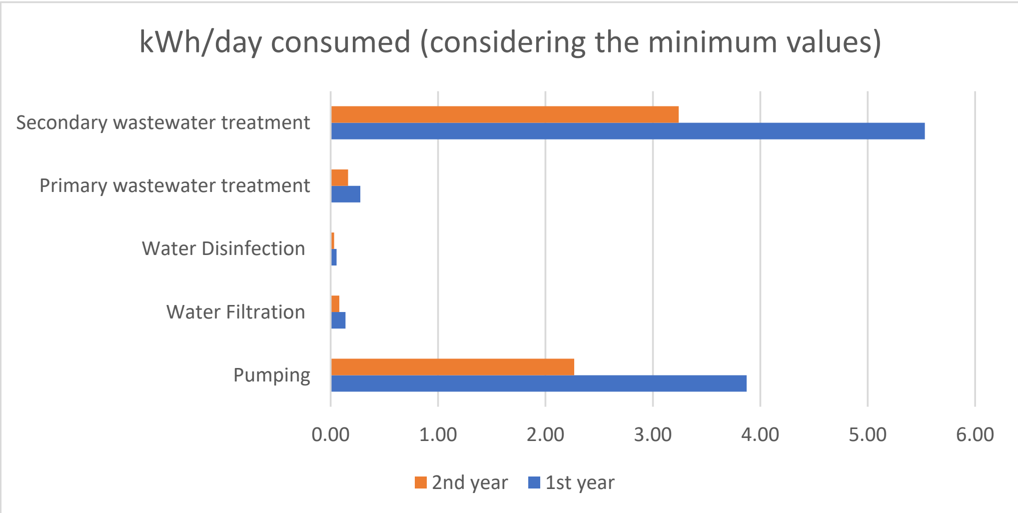

Figure 3. Energy consumption in the winery, considering the minimum values referred to in the literature, for each process.

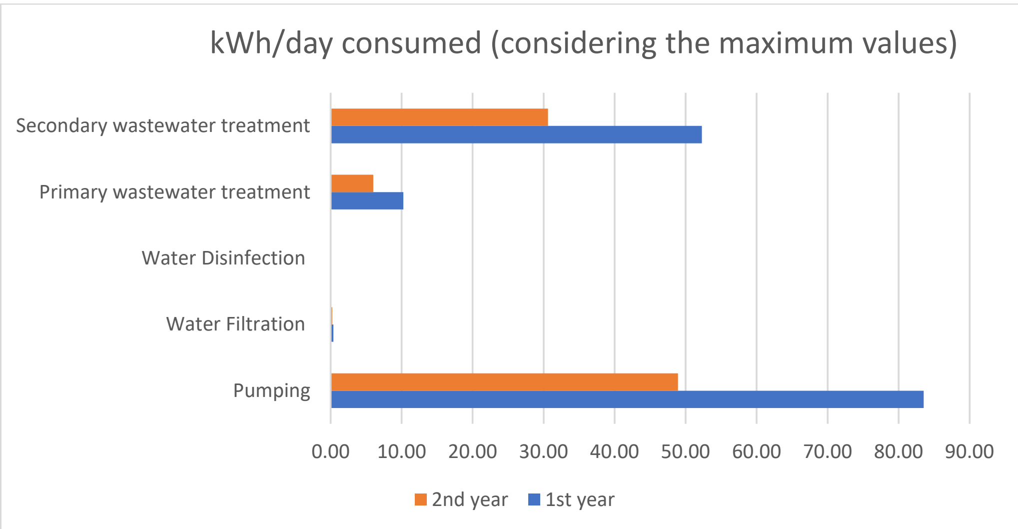

Figure 4. Energy consumption in the winery, considering the maximum values referred to in the literature, for each process.

Considering the total energy consumption within the winery, values higher than 140 kWh/day can be reached (which are quite large values) (Figure 5).

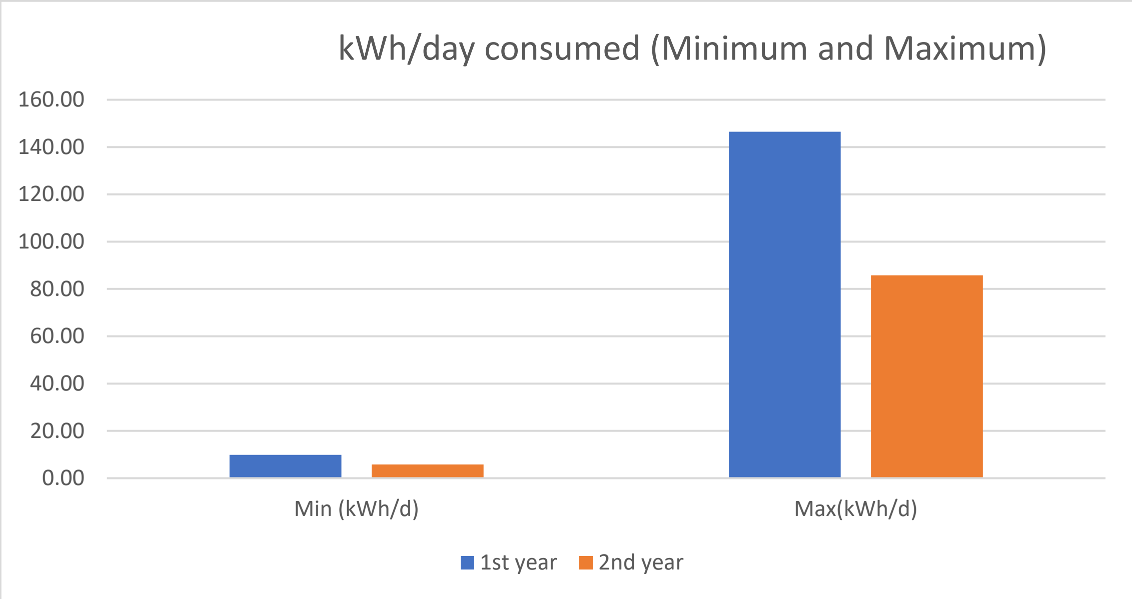

Figure 5. Average energy consumption in the winery in the two years, considering all the energy-consuming processes.

As expected, the related CO_2 emissions follow the same tendency of the energy consumption used as an emission factor to calculate CO_2 emissions (Figure 6). In this case, total emissions of more than 50 kgCO_2/day may be achieved, which are important values. Considering that energy is used from the water extraction point until the point where water returns to the natural system [61], a combined approach for reducing energy and water consumption (like dry cleaning with squeegees and brooms before any other water cleaning processes; cleaning with pressurized hot water and the use of foam cleaning solutions) will be extremely important to improve the inter-relationship between energy and water, and consequently to decrease CO_2 emissions.

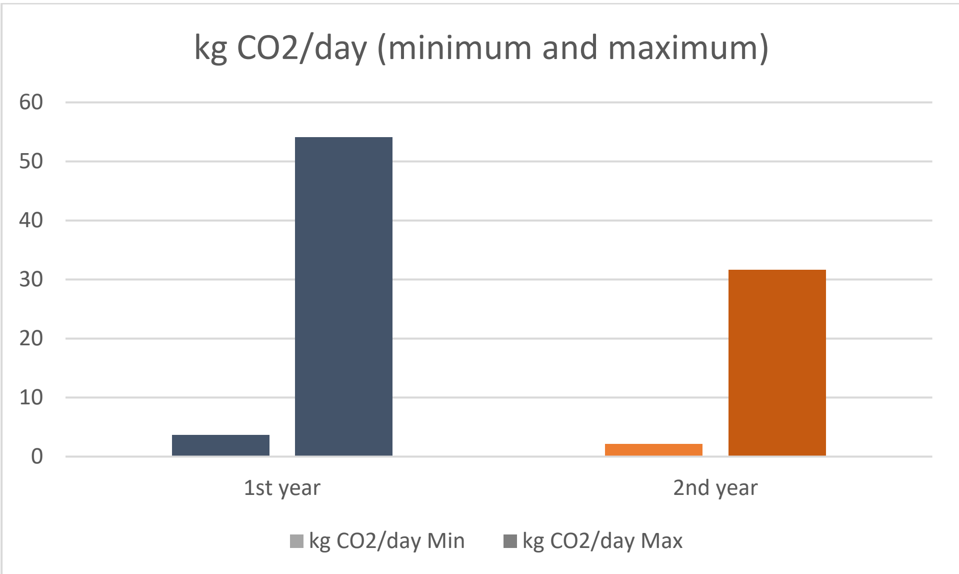

Figure 6. Total CO_2 emissions in the winery in the two years, considering all the processes.

4. Conclusions

In this case study on winery, considering the total energy consumption within the winery, values of more than 140 kWh/day were achieved. According to the total CO_2 emissions, more than 50 kgCO_2/day were also achieved in this study.

The critical point in the sustainability of the winery industry is the capability to reasonably acquire, use, process, and discharge quality water back into the environment or for reuse (for reuse in irrigation, for instance). Water management faces major challenges due to increasing reservations caused by climate change and fast fluctuating socio-economic boundary conditions. The variability of water resources available over time, unpredictable rainfall, associated climate changes, the intensification of agriculture and industries, and an increasing population lead to major water consumption and management challenges with policy implications in the short term. Making water management more adaptive and flexible is essential under fast-shifting socio-economic conditions and climate changes. Wine companies are currently adopting more sustainable philosophies, changing their practices to achieve these goals, and improving not only water efficiency but also codependent energy consumption and CO_2 emissions.

This paper contributes to enlarging the database of environmental data in one of the most important wine regions in the world (Douro Region in Portugal), which is required to bring environmental improvement. In fact, in Portugal, there is a considerable lack of information related to the impact of wineries on water and energy consumption, which is why there is still a significant volume of work to be done on this matter. This paper represents a contribution, presenting a specific case study that may be used in other cases where there is an interest in improving sustainability.

This study may bring environmental awareness to the stakeholders for the proper use of water, and its consequences, related to energy to water use and associated CO_2 emissions. Implementing the best accessible practices, moving to sustainable production, and decreasing the impact on natural resources are goals for the wine industry. The reduction of wineries' water/energy consumption is also essential.

Recognizing the limitations of this study based on a mix of bibliography and real winery collected data, in further research, we intend to expand these studies to more wineries, with more real data measures from several different size wineries. Future work will be developed to identify the level of alignment of the various actors in the wine industry concerning the importance and implementation of sustainable practices.

More sustainable practices are demanded in agriculture to improve sustainability, which is one of the main goals of the 2030 Agenda for Sustainability Development, boosting the implementation of more sustainable methods and technologies. In the resource-intensive scheme within which this activity is operating, it will be necessary to create new attitudes.

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