Journal of Social Sciences *Vol. VII, no. 4 (2024), pp. 30 - 41*
Fascicle *Social Science* *ISSN 2587-3490*
Topic *Economics and Management* *eISSN 2587-3504*

https://doi.org/10.52326/jss.utm.2024.7(4).03
UDC 663.2

ASSESSMENT OF SUSTAINABILITY PROGRESS INDICATORS IN THE WINE INDUSTRY

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Received: 10. 19. 2024
Accepted: 11. 22. 2024

Abstract. In the context of climate change, wine businesses face the challenge of adapting their business models to promote sustainable development. This requires a careful balance between the economic, social and environmental dimensions of their activities. To measure progress towards sustainability in the wine sector, it is crucial to develop a set of comprehensive indicators. This study aims to analyze sustainability indicators within the wine industry, as presented in current literature and existing research. The study highlights the importance of effective management of waste and by-products in winemaking to reduce environmental impact and create new economic opportunities. It presents a set of indicators for monitoring environmental, economic, and social dimensions of sustainability, emphasizing the need for a balanced approach to ensure the viability and progress of the sector.

Keywords: *wine industry, sustainable development, water footprint, carbon footprint, sustainable indicators.*

Rezumat. În contextul schimbărilor climatice, întreprinderile vitivinicole se confruntă cu provocarea de a-și adapta modelele de afaceri pentru a promova dezvoltarea durabilă. Aceasta necesită o echilibrare atentă între dimensiunile economice, sociale și de mediu ale activităților lor. Pentru a evalua progresele în direcția durabilității, este crucial să se dezvolte un set concret de indicatori. Studiul de față analizează indicatorii care ar putea măsura sustenabilitate întreprinderilor din sectorul vitivinicol. Cercetarea propune un set de indicatori pentru monitorizarea aspectelor de mediu, economice și sociale ale dezvoltării durabile, subliniind necesitatea unei abordări integrate pentru a asigura viabilitatea și dezvoltarea continuă a sectorului.

Cuvinte cheie: *industria vinului, dezvoltare durabilă, amprenta de apă, amprenta de carbon, indicatori de sustenabilitate.*

1. Introduction

Today's society is confronting unprecedented challenges related to climate change, which is leading to extreme natural disasters such as storms, wildfires, floods, acid rain, and droughts. Issues such as biodiversity loss, resource scarcity, and severe pollution of water, air,

and soil are directly impacting human health and living conditions, as well as hindering economic interests and the capacity for sustainable development.

The rate of resource consumption is so high that it compromises the well-being of future generations. According to United Nations projections, if this trend continues, humanity will require the resources of two Earths by 2030 to maintain its current functionality. The empirical data on Earth's condition suggests that we are exceeding its planetary boundaries. At present, 1.75 Earths would be necessary to sustain the global demand for resources [1].

In light of the significant depletion of natural resources, the rapid decline in air, water, and soil quality, increased urbanization, the depletion of the ozone layer, and damage to natural ecosystems, combined with the continuous rise in global population, it is essential to explore new approaches to production and consumption. The demands of the modern world underscore the urgency of adopting environmental sustainability as a priority objective across all industries. Furthermore, sustainable development has become one of the primary goals of the European Union (EU) and other international organizations, emphasizing the need for collective action and innovative solutions. This aspiration is reflected in policies and initiatives to promote sustainable practices in various sectors, including the wine industry.

The Republic of Moldova, through its international commitments and alignment with the 2030 Agenda for Sustainable Development, the Association Agreement with the EU and its candidate country status, shows a firm determination in promoting sustainable development and circular economy. These efforts are directly aligned with the Sustainable Development Goals (SDGs), a set of 17 global targets aimed at eradicating poverty, protecting the planet, and ensuring peace and prosperity for all now and into the future [2]. The objectives are reflected in the National Development Strategy "European Moldova 2030", the Program for Promoting the European Economy together with the Action Plan for 2022-27, the Environmental Strategy 2030, the Moldova 2050 Energy Strategy, the draft law on climate action 2024, etc.

The wine industry is an essential pillar of the Moldovan economy, playing a key role in crucial role in economic development and offering clear prospects for achieving the objectives of the economy circular economy through the efficient management of by-products. Improper wine production practices can adversely affect sustainable development. The use of pesticides and fertilizers in grape cultivation can lead to environmental issues such as air pollution, water contamination, and soil erosion [3].

In this context, wineries are encouraged to adopt business models that integrate the principles of sustainable development, balancing economic, social and environmental aspects.

In order to remain competitive, Moldovan wineries must adopt sustainable practices in both viticulture and wine production. This not only contributes to the achievement of the Sustainable Development Goals set out in the UN Agenda for Sustainable Development, but also strengthens the image and brand of the companies as consumers become increasingly aware of the environmental impact of the products they choose.

It is well known that considerable amounts of waste and by-products are generated in the production of wine. These can be reintroduced into new industrial circuits and create significant economic and environmental impacts. In order to assess the extent to which the economic value of products, materials and resources is being maintained, as well as information on waste generation and recovery, it is necessary to establish a clear framework for monitoring progress towards sustainability. A clearly defined KPI (key performance

indicator) system is essential for identifying the processes that have the greatest impact on environmental, social, and economic aspects of vineyard management and wine marketing.

This framework would allow data on waste generation and recovery to be collected and analyzed, contributing to a comprehensive picture of the benefits of the circular economy.

2. Materials and Methods

The methodology of this research is grounded in systemic, inductive, and deductive approaches. It integrates analysis, synthesis, and comparison to develop a comprehensive understanding of the framework for monitoring progress towards sustainable development in the wine sector. The analysis includes relevant studies and existing research on carbon footprint and water footprint in the wine industry. It suggests indicators to track progress towards sustainable development across these three areas. The research also examines methodologies for calculating these indicators and explores software tools available for measuring carbon and water footprints.

3. Assessing Sustainability Principles in the Wine Sector: Social, Environmental and Economic Aspects

The winemaking sector remains one of the most important branches of the agri-food industry in the Republic of Moldova, playing a strategic role with notable economic, social, and cultural significance. From 2018 to 2022, Moldova's annual wine production varied from 1.9 mhL to 1.40 mhL, Table 1.

Table 1

The trend of wine production in Moldova

Criteria	2018	2019	2020	2021	2022
Wine production, Moldova, mhL	1.90	1.46	0.92	1.43	1.40
Variation compared to the previous year	**5.5**	**-23.2**	**-37.0**	**55.4**	**-2.1**
Wine production, global, mhL	295	258	262	260	262
Variation compared to the previous year	**18.7**	**-12.5**	**1.7**	**-0.6**	**0.6**
Proportion of wine production in global production, %	0.64	0.57	0.35	0.55	0.53

Source: Elaborated by author based on OIV.

Wine production in Moldova has not followed a consistent trend, exhibiting significant year-to-year fluctuations. These variations have been driven by several factors, including the availability and quality of raw materials, economic and market conditions, political influences such as Russian embargoes, and high stock levels from previous years. The most notable decline occurred in 2020 when severe drought conditions significantly reduced raw material availability, resulting in a 37% decrease in production compared to the previous year.

Moldova's wine industry is undergoing significant transformation, with ambitions to align its future with that of the European Union and establish itself as a respected member of the international community of quality wine producers.

In recent years, the popularity of sustainable wine practices has rapidly increased. Farmers, producers, distributors, and research institutions in the wine industry are becoming increasingly interested in and involved with the transition towards sustainable winemaking.

The wine production process generates substantial amounts of waste and by-products. The by-products, includes pomace, grape marc, yeast which can be utilized in various ways

to enhance value and contribute to the overall sustainability of the process. Efficient management of these by-products is crucial not only for reducing environmental impact but also for creating new economic opportunities. Failing to process these by-products can result in a substantial pollution burden equivalent to that generated by millions of people. Additionally, some wine waste contains toxic substances, such as Prussian Blue, which is classified as Class I toxic, highlighting the urgent need for responsible management practices.

According to **National Office of Vine and Wine** in the Republic of Moldova, the wine sector generated the following quantities of by-products from 2019 to 2022, Table 2.

Table 2

By-products in the wine sector of the Republic of Moldova

	2019	**2020**	**2021**	**2022**
Grape marc, t	39253	27415	38568	41000
Yeast, hL	94652	60389	87977	No data
Grape stems, t	12144	22 721	11883	14000

Source: Based on information provided by ONVV (National Office of Vine and Wine).

During the analyzed period of 2019-2023, fluctuations in the quantities of generated wine by-products are observed, which are strictly dependent on the amount of grapes processed. This information reveals the potential for the industry to valorize by-products and continue to add value to the sector. Currently, considerable amounts of by-products are not valorized, negatively affecting the environment.

The International Organization of Vine and Wine (OIV) identifies five key principles of sustainability in viticulture that businesses need to consider [4]:

Principle 1: The sustainable approach integrates environmental, social and economic aspects in a balanced way;

Principle 2: Sustainable viticulture respects the environment;

Principle 3: Sustainable viticulture contributes to the well-being of local communities and preserves regional traditions and values;

Principle 4: Sustainable winegrowing seeks to maintain economic viability;

Principle 5: Sustainable initiatives require continuous planning and evaluation to ensure effectiveness and constant improvement of sustainable practices.

The first principle assumes that the sustainable development of the wine sector can be achieved through a balance between three key dimensions: environment, economy and society [4]. The 2nd principle concerns the protection of natural capital such as soil, water, air and biodiversity by reducing the negative impacts of winegrowing activities, including erosion, pollution, greenhouse gas emissions. Principle 3 concerns the social dimension and the impact of winegrowing activities on local communities, the welfare of workers and the preservation of regional culture and traditions. The 4th principle looks at the economic dimension to ensure the viability and profitability of wine enterprises while promoting sustainability. This involves adopting efficient practices, such as the rational use of resources, reducing production costs, proper stock management and seeking new markets and opportunities. The fifth principle implies the need to plan, assess and monitor progress towards sustainable development.

In order to monitor progress towards sustainable development of the sector, a concrete set of indicators on each dimension is needed.

4. LCA Tool as a Method for Environmental Performance Assessment in the Wine Industry

The literature review and the existing research on sustainability indicators in the wine industry, highlights the LCA (Life Cycle Assessment) tool. LCA allows the environmental performance of products to be analyzed by examining all aspects of the supply chain, from the extraction of raw materials and the manufacture of additives, to the use and disposal of packaging materials. The LCA tool is covered by international standards (ISO 14000 series) and is recognized worldwide.

Law No. 209 of 29-07-2016 of the Republic of Moldova defines it as: **"the assessment, in relation to a product, of the effects on the environment caused by the production, distribution, marketing and use of the product, including its recovery and disposal, as well as the use of energy and raw materials and waste produced from any of the above activities"**[5].

LCA considers four impact categories: carbon footprint (CF), abiotic depletion (AD), acidification potential (AP) and eutrophication potential (EP) [6].

The assessment process consists of four distinct stages: defining the goals, conducting an inventory analysis, performing an impact assessment, and interpreting the results, Figure 1.

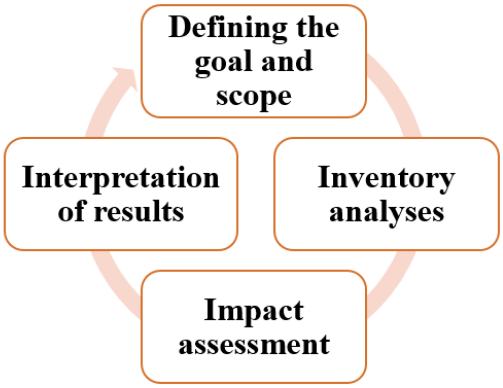

Figure 1. The key stages of life cycle assessment LCA.
Source: developed by author based on [3].

A central issue in assessing the environmental performance of a product through the life cycle assessment (LCA) is the data collection phase or Life Cycle Inventory (LCI), which can influence the overall level of quality of the study.

In fact, the flow of each product system depends on several variables that need to be considered during data collection. The enterprise should collect data on water, energy, fertilizer, chemical and fuel consumption at all stages of the production process, including transport and distribution. In the case of viticulture, the main inputs are: water, electricity, fuels, products used in vineyards and cellars (fertilizers, plant protection products, oenological products, auxiliary materials, etc.[7].

Many governments have funded the creation of LCI databases for agricultural analysis in their country, as this public investment is essential to provide reliable information for use in evidence-based public policy making. Another important issue in LCA studies applied to the wine sector concerns the regulatory issues related to the "designation of origin" associated with wine products. A „designation of origin" means a wine product whose production belongs to a particular geographical context; in the case of Europe, this corresponds to wines with Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). In Australia, the primary data for calculating the LCA is drawn from the

Sustainable Winegrowing Australia records for winery management, a national sustainability program of the Australian wine industry. This program is modeled on global industry best practices and aligned with the UN SDG Agenda. Industry progress towards achieving the SDGs is monitored annually. Participation in the program is voluntary and all members annually provide a standardized set of data on production and resource use, including water, fertilizer, electricity and fuel in the production process [8].

There are specialized software that facilitates the calculation of life cycle analysis (LCA) once primary data is entered into the system, such as SimaPro, OpenLCA, CMLCA and others [9-11]. The primary data needed to calculate the LCA are very detailed and include aspects such as: the number of soil treatments applied in the vineyard, the type of fuel used, the type of energy used in production, the technologies applied, the type of packaging used, the label weight, the type of vehicles used, the transportation routes and others. Climate changes, such as higher temperatures, extreme weather events and variations in rainfall patterns, can have an impact on the growth and development of grapes, leading to lower yields, earlier or later harvests and possibly lower quality wine. It is therefore recommended when assessing environmental performance using the LCA method to collect data from at least three reference years and this is the most commonly adopted approach [12]. Life Cycle Assessment (LCA) of wine production assesses the environmental impact of the entire process, from the production of the raw material (grapes) to the consumption of the finished product and the disposal of the packaging. The process is divided into distinct activities: viticulture (production of the raw material), vinification (production of the wine), packaging and distribution to the consumer [13].

5. Measuring carbon footprint and water footprint in the wine industry

LCA is a complex tool to measure progress towards sustainable development. Carbon footprint (CF) is considered the most relevant indicator in Life Cycle Assessment (LCA) methodologies for assessing greenhouse gas emissions from the wine industry. The carbon footprint indicator CF, within an LCA approach, quantifies the direct and indirect greenhouse gas emissions (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) during the life cycle of a given product/service/activity. These emissions are expressed in units of carbon dioxide equivalent (CO_2eq). There are several general rules for calculating the carbon footprint, including ISO-14064, ISO-14069, ISO 14067, PAS 2050, PAS 2060, the GHG Protocol and Verified Carbon Standard (VCS), PEFCR and the Bilan Carbone method. Carbon footprinting has some advantages over LCA when it comes to communicating with stakeholders and the general public, as the interpretation of the results is simpler and easier to understand, making the information more accessible to all. There are applications that calculate the carbon footprint of a product, service, work, activity. In the wine industry there are websites offering carbon footprint calculators such as WineGB or Australian wine carbon calculator[14, 15]. In order to be able to calculate the carbon footprint of wine, companies need to collect accurate information on energy consumption, fuel, waste, raw materials, transportation, equipment, technologies, etc.

Navarro et al. (2016) calculated the carbon footprint of French and Spanish wines produced in eighteen wineries (including three wine cooperatives), with vineyards in seven production regions and fourteen distinct appellations. The results showed an average of 0.85 kg CO_2 equivalent per 0.75 L bottle of wine. The main contributors to this footprint were emissions from bottle production (45.6%), fuel production and combustion (15.6%), followed by electricity generation, with a contribution of 10.1% to the total footprint, Table 3 [16].

Table 3

The carbon footprint of wine according to Navarro

Packaging/Bottle Filling	**Percentage**
Glass Residues	0.70
Cardboard Production	3.10
Plastic Production	0.40
Glass Production	45.60
Wine Production	
Solid Waste	1.70
Fuel Production	0.80
Production of Basic Auxiliary Materials for Wine	2.30
Wastewater	0.001
Fuel Combustion	3.80
Electricity Production	9.20
Chemical Emissions	5.30
Viticulture	
Fuel Production	1.20
Electricity Production	0.90
Manufacturing of Plant Protection Products	6.10
Fertilizer Production	8.80
Emissions from Fuel Combustion	10.10

Source: Based on [16].

Another indicator related to the environmental dimension of sustainable development is the WaterFootprint. The concept of a "water footprint" was introduced by Hoekstra and Hung (2002) and further developed by Chapagain and Hoekstra (2004) as a useful tool that indicates and quantifies trends in water scarcity and pollution. Water footprint assessment is a useful tool for quantifying water use along the supply chain, providing valuable information on potential impacts on local watersheds and water availability for future periods [17].

The calculation of the water footprint is based on a product life-cycle assessment that includes all direct and indirect processes that consume water from the beginning (e.g. grape production) to the end of the life-cycle of the final product [18]. The water footprint varies depending on climate and local conditions, crop irrigation technology, location, winemaking technology and even the type of wine produced.

According to research carried out by members of the Water Footprint Network, the global average water footprint of grapes is 610 L/kg. Considering that an average of 0.7 L of wine is produced from 0.7 L of grapes, the water footprint of wine would be about 870 L of water per L of wine [19]. On average, 109 L of water would be used to produce a 125 mL glass of wine.

6. Complementary indicators measuring progress towards sustainable development of the wine sector

In the wine industry, indicators such as LCA, carbon footprint and water footprint are widely used to assess environmental performance, which is only one part of sustainable development. Sustainable development encompasses not only the environmental dimension but also the economic and social dimensions. Environmental, social, and economic criteria

have become essential tools for companies across various sectors to assess their current sustainability performance.

The Table below presents a series of indicators to measure progress in the sustainable development of a wine enterprise. These indicators are grouped into the three aspects of sustainable development: environmental, economic and social, Table 4.

Table 4

Indicators for assessing the environmental dimension of sustainable development

Indicator Category	Indicator Description
Environmental Policy	Certification for sustainable production
Energy Use	Energy consumption per production unit
	Proportion of energy consumed from renewable sources
Resource Use	Total amount of fertilizers used (kg/ha)
	Proportion of organic fertilizers in the total used fertilizers
	Number of phytosanitary treatments applied
	Bottle weight
	Rate of valorization of by-products
	Use of eco-labeling
Water Use	Number of phytosanitary treatments applied
	Total water consumption for irrigation (m^3/ha/year)
	Water consumption in wine production (m^3/dal)
	Water footprint of wine

Source: Elaborated by authour based on [20, 21].

The environmental dimension of sustainability in the wine sector encompasses various indicators that measure the impact of production processes and resource use. These indicators are categorized into several key areas: Environmental Policy, Energy Use, Resource Use, Water Use.

Among the proposed indicators are several key metrics designed to measure sustainability in the wine sector. These include the **proportion of energy consumed from renewable sources**, which reflects the shift towards greener energy practices. Another indicator covering the environmental dimension is **water consumption in wine production,** which highlights the efficiency of water use throughout the production process. The **rate of valorization of by-products** assesses how effectively the industry utilizes secondary products generated during production. T**otal amount of fertilizers used (kg/ha)** provides insight into the environmental impact of fertilization practices.

The economic dimension of sustainability in the wine sector addresses factors that contribute to the financial stability and long-term success of the industry. Key areas include: Economic Feasibility, Productivity and Efficiency, Digital Transformation and R&D, and Market Access and Exports. Each of these categories is associated with specific indicators designed to track a company's progress toward sustainable development.

Among the proposed indicators for monitoring progress in the economic dimension of sustainable development are: the percentage of investment in green and sustainable technologies and energy-efficient equipment, labor productivity, the number of new eco-friendly products developed, and investments in research and development, among others, Table 5.

Table 5

Indicators for assessing the economic aspects of sustainable development

Indicator Category	Indicator Description
Economic Feasibility	Circular business model
	Percentage of investment in green and sustainable technologies and energy-efficient equipment
Productivity and Efficiency	Labor productivity
	Production cost per unit
Digital Transformation and R&D	Investments in research and development
	Number of new eco-friendly products developed
	Level of digitalization
Market Access and Exports	Customer satisfaction rate
	Export volume
	Export value
	Market diversity

Source: Elaborated by authour based on [20, 21].

The social dimension examines the company's interactions with other businesses and the local community where it operates. It focuses on aspects related to personnel, such as safe working conditions, training programs, workplace ergonomics. It also promotes employee involvement in organizational decisions and supports social responsibility through positive contributions to the local community. Table 6 outlines a comprehensive set of indicators designed to evaluate key aspects of social responsibility and ethical practices within an organization. Each category focuses on particular aspects that are necessary to support sustainable development and create a positive work environment.

Table 6

Indicators for assessing the social dimension for sustainable development

Indicator Category	Indicator Description
Business Ethics	Code of conduct
Working Environment	Employee satisfaction
	Clear procedures for remuneration and working conditions
	Number of complaints or internal conflicts
Training and Professional Development	Number of programs for employee development
	Number of trained individuals
	Number of training hours per employee per year
Gender Equality	Proportion of women in the workforce and in leadership positions
	Employment rate of individuals from vulnerable groups
Social Responsibility and Community	Investment in community projects

Source: Elaborated by authour based on [20, 21].

The Business Ethics category includes a code of conduct that sets standards for moral behavior within the company. The Working Environment section measures employee well-being by assessing employee satisfaction, the transparency of compensation practices, and the number of complaints to monitor raised concerns.

The Training and Professional Development section focuses on employee growth by counting skill-enhancement programs, measuring the number of trained personnel, and evaluating training investment through the number of training hours per employee.

The Gender Equality category assesses diversity by examining the percentage of women in leadership positions and the overall workforce, as well as the employment rate of individuals from marginalized groups. Finally, the Social Responsibility and Community category evaluates the organization's impact through its investments in community initiatives.

Conclusions

To remain competitive in the international market and in accordance with the legal and regulatory framework for transitioning to sustainable development and adopting environmentally friendly production practices, businesses in the wine sector must focus on sustainability. This involves balancing social, economic, and environmental aspects. To assess how sustainable a business is, how circular its business model is, and the progress it has made towards sustainability, a set of indicators needs to be developed. These indicators should be designed for ease of calculation by the business. Currently, there are specialized software tools for calculating sustainability indicators, but businesses need to track various inputs such as water, energy, fertilizer, chemicals, and fuel consumption throughout all stages of the production process, including transport and distribution. In viticulture, the main inputs are water, electricity, fuels, and products used in vineyards and cellars (such as fertilizers, plant protection products, oenological products, and auxiliary materials).

Currently, many companies still operate using linear business models based on the "take, make, dispose" principle. There is also no framework in place to monitor progress towards sustainable development in the wine sector of the Republic of Moldova. However, it is certain that in the coming years, adopting sustainable practices will become a necessity for exporting and for maintaining and growing the customer base. Consumers are increasingly recognizing the importance of nature in the sustainability of our planet and tend to prefer purchasing from companies that produce in harmony with the environment. Recording, evaluating, and publishing progress toward sustainable development through sustainability reports would allow businesses to be transparent with consumers, strengthen their brand, and improve their market position. Furthermore, this approach would contribute to achieving the goals outlined in the UN Agenda, the European Green Deal, and the EU Circular Economy Action Plan.

Acknowledgments. This research was developed within the framework of the Institutional Research Program of the Technical University of Moldova (2024-2027), subprogram code 020408, „Research on Ensuring Sustainable Development and Increasing the Competitiveness of the Republic of Moldova in the European Context”.

Conflicts of Interest: The author declares no conflict of interest.

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Citation: Diaconu, C. Assessment of sustainability progress indicators in the wine industry. *Journal of Social Sciences* 2024, 7 (4), pp. 30-41. https://doi.org/10.52326/jss.utm.2024.7(4).03.

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