

BIOENERGY USE OF VITICULTURE WASTE: CHALLENGES AND OPPORTUNITIES IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Modern challenges related to the energy crisis, rising prices for traditional energy sources, and the need to ensure environmental safety are driving the search for alternative energy sources. One promising area is the use of agricultural waste for the production of biofuel products. Viticulture waste deserves special attention, in particular grapevines, which are produced in significant quantities every year and are usually disposed of inefficiently by burning in the fields. This practice leads to greenhouse gas emissions, soil degradation and poses risks to the environmental safety of regions.

At the same time, the production of fuel pellets from grapevines and other plant residues can be an effective tool for sustainable development, combining environmental and economic benefits. Firstly, it minimises the negative impact on the environment through the utilisation of agricultural waste. Secondly, it creates an additional source of renewable energy, which increases the level of energy independence of both individual enterprises and the country as a whole. Thirdly, the development of bioenergy opens up new opportunities for Ukraine's integration into European environmental and energy programmes.

In European Union countries, the use of waste from viticulture and horticulture as a bioenergy resource is one of the areas of green energy. Every year, wine-producing regions (France, Spain, Italy, Portugal, Greece) generate significant amounts of waste in the form of vines, leaves and vineyard pruning residues. The European approach is based on the concept of a circular economy, where plant residues are considered a valuable raw material for energy production. Pilot and industrial projects for the production of pellets and briquettes from grapevine waste are actively underway in France and Spain. For example, in the Languedoc-Roussillon region (France), there are programmes for processing vineyard waste into pellets, which are used to heat wineries and local municipal facilities. In Italy (Veneto and Tuscany regions), vine shoots are used as fuel in cogeneration plants, which allows not only heat but also electricity to be generated.

European programmes supporting green energy (Horizon 2020, LIFE, CAP) encourage farms to implement technologies for collecting and processing grapevine waste into biofuel. This contributes to reducing CO₂ emissions, increasing the energy independence of regions and creating added value in the agricultural sector.

In Ukraine, regulatory support in the field of renewable energy and waste management is undergoing active development and adaptation to European standards. The Law of Ukraine «On Alternative Energy Sources» defines the legal basis for the use of biomass as an energy resource. The Law of Ukraine «On Alternative Types of Fuel» establishes conditions for the production and use of biofuels, in particular pellets. «The National Renewable Energy Action Plan for the period up to 2030» envisages an increase in the share of bioenergy in the energy consumption structure. In 2022, the Law of Ukraine «On Waste Management» was adopted, which is harmonised with EU Directives and enshrines the principles of the waste management hierarchy: from prevention to reuse, recycling and energy recovery. Under the Association Agreement with the EU, Ukraine has committed to implementing the provisions of the European Green Deal. This includes reducing greenhouse gas emissions, developing renewable energy (including promoting the use of biomass for heat and electricity production), and transitioning to a carbon neutral economy by 2050. Thus, Ukraine is gradually forming a legislative and institutional framework for the development of bioenergy, integrating European approaches and opening up prospects for the use of agricultural waste as an alternative energy source in the context of sustainable development.

Using the example of a company in the Mykolaiv region (FOP «Gorin Dmitry Borisovich»), which specialises in the production of pellets from grapevine waste and plant residues, the challenges and prospects of bioenergy use of agricultural waste in the context of sustainable development are considered. The use of SWOT analysis allows us to identify the strengths and weaknesses of such production, outline its opportunities and potential threats, which is important for the formation of effective development strategies in the context of Ukraine's current crisis challenges (Table 1). This approach enables the company to respond promptly to market challenges, optimise resource utilisation and increase the competitiveness of biofuel products.

The production of fuel pellets from grape, vine and other plant residues takes place in several stages. The first step is to collect waste from grapes, vines and other plants, such as branches, leaves, stems, etc. These materials can be used for pellet production. Next, the raw materials are dried to the optimum moisture content (10–15%). After that, the vines and other plant residues are crushed in chopping machines and then in hammer mills to fractions of 3–8 mm. The prepared mass is fed into a granulator, where high pressure and temperature form dense pellets. The final stage involves cooling in special coolers and packaging the pellets using automated packaging lines for further use as biofuel.

Table 1. SWOT analysis of pellet production from grapevine waste and plant residues

Strengths	Weaknesses
1. Significant volumes of available raw materials (grape vines, garden and agricultural waste). 2. Environmentally friendly waste disposal instead of incineration. 3. Compliance with European trends in green energy. 4. Opportunity to reduce CO₂ emissions and improve environmental safety. 5. Positive image of the enterprise.	1. Seasonality of biomass harvesting (dependence on vineyard pruning cycles). 2. Agricultural waste requires drying, which leads to increased production costs. 3. Limited financial resources for equipment modernisation. 4. Underdeveloped domestic market for pellets. 5. Lack of sufficient number of bioenergy specialists in the region.
Opportunities	Threat
1. Integration into European programmes (Horizon Europe; Creative Europe; LIFE, etc.). 2. Expansion of the sales market (utility companies, agricultural sector, exports to the EU). 3. Obtaining green investments, grants and preferential loans. 4. Use of innovative technologies to improve energy efficiency. 5. Creation of new jobs and development of local communities.	1. Competition with other types of biofuel (wood pellets, straw pellets). 2. Instability of national legislation in the field of renewable energy sources and waste management. 3. Logistical difficulties caused by military actions and damage to critical infrastructure. 4. Fluctuations in energy prices affecting the competitiveness of pellets. 5. Climate change risks affecting grape yields and raw material availability.

The SWOT analysis revealed a number of strengths, including the availability of a stable raw material base (grapevine waste and other plant residues), compliance with current green energy trends, and integration into European environmental approaches. To strengthen these factors, it is advisable to:

- introduce modern technologies for collecting and preparing biomass, which increases production efficiency;
- expand investment in equipment modernisation;
- stimulate demand for pellets by concluding long-term contracts with municipal enterprises and agribusinesses;
- more actively integrate the enterprise into European renewable energy support programmes.

With regard to weaknesses and threats, the main challenges are the seasonality of raw material procurement, the instability of national legislation, and competition from other types of fuel. The following measures are important to minimise these challenges:

- the creation of regional logistics centres for the storage and preparation of biomass, which will reduce the risks of seasonality;
- strengthening state support in the form of green loans, tax incentives and guarantees for biofuel sales;
- harmonising legislation with EU directives on renewable energy and waste management;
- conducting information campaigns among the population and businesses to increase confidence in biofuels.

An important aspect is the possibility of scaling the experience of the Mykolaiv region enterprise to other regions of Ukraine. The development of pellet production from grapevines and agricultural waste can become part of regional waste management programmes and energy independence strategies. In particular, in the southern and central regions of Ukraine, where large areas of vineyards and orchards are concentrated, it is advisable to create such bioenergy clusters. This will contribute to the creation of new jobs, diversification of the local economy and reduction of greenhouse gas emissions.

It is also necessary to take into account European experience, where bioenergy clusters have become part of the local circular economy and have made it possible to optimise the management of agricultural waste. The implementation of similar initiatives in Ukraine could help attract international investment and accelerate integration into the European energy space.

Thus, SWOT analysis confirmed that the production of pellets from grapevines not only has high development potential, but can also be effectively integrated into Ukraine's sustainable development strategy, ensuring a balance between economic benefits, environmental safety and social responsibility. In the long term, this will make an important contribution to achieving climate goals and improving the country's energy security.