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STIMULATING GREEN ENERGY FOR CONSUMERS: A STUDY ON BIOFUEL POLICY AND CIRCULAR ECONOMY PATHWAYS IN MOLDOVA

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Abstract
This study analyzes the economic and policy dimensions of biofuel development in the Republic of Moldova in the context of its transition toward a circular and consumer-oriented economy. With transport energy demand fully dependent on fossil fuel imports and limited domestic refining capacity, Moldova faces structural barriers in achieving its Renewable Energy Sources in Transport (RES-T) targets set by RED II and national legislation (Law No. 10/2016). The paper examines production cost scenarios and incentive strategies for first- and second-generation biofuels – bioethanol and biodiesel – based on local feedstocks such as corn, sunflower oil, sugar beet, and DDGS. Supply chain modeling reveals that domestic production of cereal-based bioethanol is the most feasible in the short term, while advanced biofuels from waste residues are constrained by technology costs and infrastructure gaps. The analysis further explores the role of Free Economic Zones (FEZs), logistics via the Giurgiulesti Port, and regional blending options as cost-reduction levers. Key stakeholders including national producers and fuel distributors are identified as ready to operationalize blending strategies under EU sustainability standards. The study concludes with short- and long-term recommendations for policy and investment strategies to strengthen Moldova's biofuel sector as part of a broader circular economy model, enhancing both energy security and consumer access to sustainable transport fuels.
Keywords: *biofuels, Moldova, renewable energy policy, circular economy, consumer transition*
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INTRODUCTION

Aligned with the 2030 targets of the Renewable Energy Directive (RED II), Moldova aims to achieve 9% of transport energy from biofuels. EU market trends show increasing demand for bioethanol and biodiesel, including advanced biofuels like UCO biodiesel and straw-based ethanol.

This paper provides an analysis of biofuel development, incentive policies, and supply chain options through Free Economic Zones. It draws from both EU

and national market conditions. Moldova, part of the EU's Eastern Partnership and the Energy Community since 2010, is committed to aligning with EU renewable energy laws, particularly RED II (Plotnic Olesea, 2022). National priorities include decarbonizing transport through biofuel integration, reflected in strategic documents like Moldova 2030, the National Energy Strategy, and the forthcoming NECP.

Law 10/2016 (transposing RED I) sets Moldova's renewable energy targets: 17% in overall energy (met in 2020) and 10% in transport by 2030. Despite success in heating/cooling, renewable energy in transport is minimal – just 0.18%, largely due to electric public transport.

Barriers include the lack of a national biofuel framework, blending mandates, and infrastructure. Amendments to Law 10/2016 now aim to scale up biofuel use and set thresholds:

- 2% cap on food-based biofuels,
- 1.7% from UCO and animal fats,
- 3.5% from advanced biofuels by 2030.

Transport represents 26% of energy use, dominated by imported fossil fuels. To meet the 9% target, Moldova must consume ~71 million liters of biofuels annually (46,640 tons biodiesel, 14,220 tons bioethanol). Achieving this requires mobilizing local feedstock, enabling infrastructure, and incentivizing investment.

1. PRELIMINARY ANALYSIS: ECONOMIC FACTORS AND INCENTIVE POLICY

This section outlines key economic factors affecting biofuel production costs in Moldova, particularly biodiesel and bioethanol, in line with Law No. 10/2018 and RED II targets for 2030.

It reviews market dynamics, production costs, and how biofuels compare with fossil fuels after blending. The analysis also highlights how fiscal policies – especially those linked to Free Economic Zones (FEZs) – influence national biofuel demand.

Additionally, it considers stakeholder interests and available production data to assess the economic viability of expanding Moldova's biofuels industry.

1.1. Preliminary Assessment of Biofuels in Moldova

Biofuel cost analysis in Moldova must consider production costs, market conditions, and legal frameworks such as RED II and the national RES Law No. 10/2016, which prioritizes local feedstocks.

Key feedstocks include corn, sunflower oil, straw, and by-products like SSDG. Advanced biofuels made from residues are eligible for double counting under RED II. The viability of biofuel production depends on:

Feedstock type and price

Harvesting and processing efficiency

Transport and distribution costs
Market competition with food/feed sectors
Volatility in fossil fuel and crop prices

EU experiences show that targeted subsidies, tax incentives, and credits (e.g., RECs) play a major role in offsetting production costs. In Moldova, Free Economic Zones (FEZs) offer opportunities to lower financial barriers and enhance industry competitiveness.

In short, Moldova's biofuel production costs are shaped by domestic agricultural practices, policy support, and global energy trends (Iarmenco Mihaela, 2020). Prioritizing local biomass and adopting RED II-aligned incentives can create a viable biofuel market.

1.2. Trends in Biofuel Costs and Technology Readiness (Shortened)

Biofuel prices are largely driven by feedstock costs and the maturity of conversion technologies.

First-generation biofuels (from corn, sugar beet, sunflower, rapeseed) are commercially viable and widely used.

Advanced biofuels, made from residues (straw, algae, lignin), offer greater sustainability but are more expensive due to immature technology (TRL 3–8) and limited scale.

Emerging technologies such as gasification, pyrolysis, and hydrothermal liquefaction remain costly but are essential for long-term decarbonization. EU policy supports these pathways through incentives and double-counting mechanisms.

Biofuel innovation also includes the use of renewable hydrogen and captured CO_2 to produce synthetic fuels (e-fuels), though still in early development.

Moldova can benefit by adopting cost-effective first-generation biofuels in the short term while gradually investing in advanced pathways aligned with EU sustainability goals.

1.2.1. Effect of Feedstock and Technology on Biofuel Costs (Shortened)

Producing transport biofuels remains more expensive than fossil fuels, requiring policy support to be economically viable. However, using lower-cost feedstocks – such as waste or residues – can reduce costs. Technologies that improve conversion efficiency or generate valuable co-products also help.

Hydrotreated vegetable oil (HVO) production is expanding in countries like Sweden due to cost-saving measures and policy incentives. In contrast, advanced biofuels from lignocellulosic materials (e.g., straw, wood) remain costly due to high investment needs and logistics.

According to the IEA (2020), production costs for advanced biofuels range between 17–44 EUR/GJ using biomass, and 13–29 EUR/GJ with waste feedstocks

– compared to fossil fuels at 8–14 EUR/GJ (as of 2019). These figures highlight feedstock and capital costs as major cost drivers.
Opportunities for cost reduction include:

a) Integration of advanced biofuels with existing plants;
b) Scaling up technology to reduce capital costs;
c) Access to cheaper finance through risk mitigation;
d) Implementation of carbon pricing to close the cost gap.

Although fossil fuel prices have fluctuated significantly (from <18 €/barrel in 2020 to >110 €/barrel in 2022), most technology and cost-related barriers remain relevant (IEA, 2024).

IEA also identifies research needs to lower costs and expand market potential, particularly for lignocellulosic ethanol and hydrocarbon biofuels. These include:

a) More efficient pre-treatment and conversion processes;
b) Novel biological strains for fuel production;
c) Advanced separation technologies;
d) Lignin valorization for fuels and bio-based products.

Despite higher costs, advanced biofuels offer long-term opportunities for decarbonizing transport and building a resilient renewable fuel market.

1.2.2. Current Biofuel Production and Use in the EU (Shortened)

The most widely used biofuels in EU transport are first-generation **bioethanol**, **biodiesel (FAME)**, and **HVO**.

a) **FAME** is now typically blended with diesel at 7–8% due to compatibility issues with modern engines.
b) **Bioethanol** is blended with gasoline at 5–7%, or used at 85% in flex-fuel vehicles.
c) **HVO** and paraffinic fuels (e.g. Fischer-Tropsch) are drop-in fuels and can fully replace fossil diesel. While often blended at 30%, pure HVO use is growing, especially in freight transport.

2. EU BIOETHANOL PRODUCTION TRENDS

Bioethanol, produced by fermenting crop-based carbohydrates, saw EU production grow from 4.8 billion liters in 2014 to 5.57 billion liters in 2023 (Fig. 1). Consumption increased steadily, driven by rising blending mandates and competitive pricing versus gasoline.

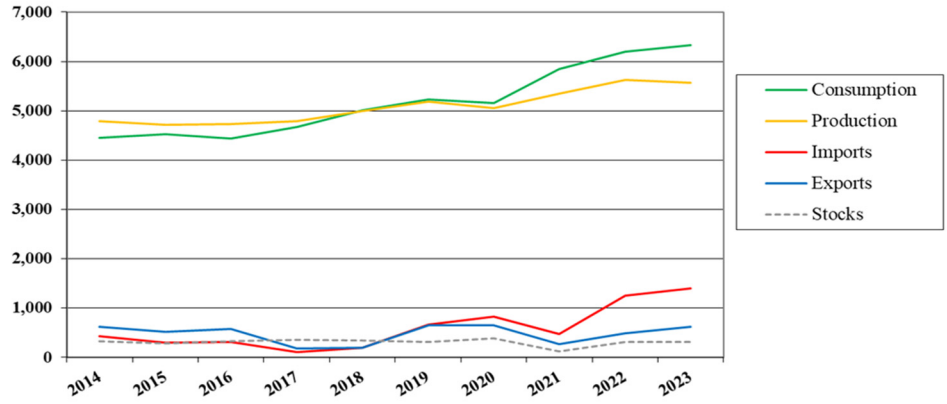

Figure 1. Millions of Liters of Bioethanol-fuel market and trend in EU (USDA, 2023)

Since 2019, the EU has become a net importer of bioethanol. In 2023, despite stronger demand, production declined due to reduced sugar beet cultivation in France.

Outlook:

- Expansion of crop-based (first-gen) bioethanol is expected to plateau due to RED II limits.
- Cellulosic (advanced) ethanol remains underdeveloped due to high costs, regulatory uncertainty, and weak supply chains.
- EU production capacity for cellulosic ethanol reached only 125 million liters in 2022.
- Advanced ethanol from non-cellulosic waste (Annex IX Part A) rose from 240 million liters in 2019 to 575 million liters in 2021 (ePURE, 2022).

In sum, while traditional bioethanol continues to grow moderately, large-scale adoption of advanced ethanol depends on clearer policies and greater investment support.

2.1. Feedstock Use and Co-product Trends in EU Bioethanol Production

EU bioethanol production continues to rely heavily on cereals – primarily corn, wheat, barley – and sugar beet. By 2023, production approached 6 billion liters, requiring an estimated 18 million tons of biomass, with ~10.2 million tons of cereals expected in 2024.

Sugar beet remains the largest feedstock, although its use is declining. Corn and wheat are increasingly used, while cellulosic biomass accounts for only 1%.

Corn imports for bioethanol mainly come from the U.S. and Ukraine. Despite the ongoing conflict, Ukraine remains a key supplier due to its non-GMO corn. Moldova plays a notable role in supplying barley to the EU, supporting feedstock diversification amid geopolitical disruptions.

Feedstock prices rose sharply in early 2022 due to the war and fuel volatility. Though prices stabilized later, the cost of bioethanol remains tied to feedstock price fluctuations, as presented in table 1.

Table 1. Cost of bioethanol in 2024

Feedstock	2024 Cost (€/liter)
Wheat	0.97
Corn	0.90
Barley	0.88
Sugar Beet	0.70

Choosing cost-effective, locally sourced feedstocks aligned with existing infrastructure will be critical for Moldova's bioethanol strategy.

2.2. Biodiesel Production Costs and Trends in the EU

Global biodiesel production reached 52 million tonnes in 2022–2023, with the EU producing ~14 million tonnes (25%). After peaking in 2019, EU production slightly declined due to COVID-19 but remains strong due to RED II mandates, especially for advanced biodiesel, as presented in table 2.

Table 2. Biodiesel production sosts per country in 2023

Top EU Producers (2023)	Production (mil. tons)
Germany	3.43
France	2.16
Spain	1.61
Italy	1.26
Netherlands	2.10

Biodiesel is mainly produced from oil crops (FAME), and hydrogenated vegetable oils (HVO). Advanced feedstocks like used cooking oil (UCO) and animal fats, listed in RED II Annex IX, are gaining market share.

Challenges: EU FAME production faces competition from cheap imports (e.g., Argentina's SME, Indonesia's PME) and some plants have shut down or operate below capacity.

HVO production is increasing due to new dedicated plants and policy incentives. While traditional FAME output may decline, advanced biodiesel is expected to grow as EU countries seek to meet climate goals and reduce fossil fuel reliance.

2.3. Feedstock Market Impacts on Biodiesel Production

Globally, biodiesel production relies mainly on vegetable oils: palm oil (36%), soybean oil (23%), and rapeseed oil (14%). Waste oils (UCO) and animal fats contribute 14% and 5%, respectively.

In the EU, agricultural crops account for 76% of biodiesel feedstock. Rapeseed oil leads with 42% of inputs, despite reduced imports from Russia. This has been partially offset by rising palm oil imports from Asia and growing use of advanced feedstocks (UCO, animal fats) listed in RED II Annex IX.

Sunflower oil usage has declined, as the EU prioritized its use for food due to supply disruptions caused by the war in Ukraine. This highlights the close link between biodiesel and food markets.

Table 3. EU Biodiesel Feedstock Composition in 2023

Feedstock	2023 Tons (1,000 Mt)	% Share
Rapeseed oil	6,375	42%
Used Cooking Oil	4,350	29%
Palm Oil	1,400	9%
Animal Fats	1,000	7%
Soybean oil	740	5%
Sunflower Oil	265	2%
Others	950	6%

Moldova remains a minor but strategic supplier, exporting around 9% of sunflower oil used for EU biodiesel.

Feedstock prices have fluctuated due to high energy costs and supply chain disruptions. Despite this, UCO-based biodiesel prices remain stable (~1,020 €/mt, March 2024) due to support from RED II's double-counting mechanism, which boosts demand and policy value.

In contrast, FAME biodiesel faces weak demand and greater volatility due to market saturation and reduced diesel use.

The growing share of advanced feedstocks (now ~24%) reflects a structural shift driven by RED II and sustainability concerns. As palm oil is gradually phased out under ILUC rules, the EU is expanding partnerships with non-EU countries – including Moldova, Ukraine, Indonesia, and Argentina – for more resilient feedstock sourcing.

3. BIOFUEL COSTS AND RES-T INCENTIVES IN MOLDOVA

This market analysis identifies key factors for advancing biofuels in Moldova:

a) 2030 Decarbonization Targets: Achieve 9% renewable energy in transport, as mandated by RED II and Moldova's RES Law (2018).
b) Current Market Status: The biofuels market remains undeveloped, with no official biofuel imports/exports despite strong feedstock availability.
c) Infrastructure: Moldova lacks refineries and blending infrastructure, hindering domestic biofuel integration.

d) Stakeholder Interests: There is emerging interest, but capacity gaps exist in production, certification, and logistics.
e) Free Economic Zones (FEZ): FEZs present strong potential to support investment in biofuel infrastructure and supply chains.

The analysis supports defining realistic pathways toward Moldova's 2030 targets, while also identifying existing barriers and policy gaps.

3.1. Current Status and Future Demand for Biofuels in Moldova

Moldova has the potential to become a producer of biofuel feedstocks (e.g., cereals, sunflower oil), yet domestic biofuel production is minimal due to the absence of blending mandates and fiscal incentives.

To meet the 9% transport energy target by 2030, according to the table 4, Moldova must integrate ~52 million liters of biofuels annually, including:

a) 36.6 million liters of biodiesel
b) 15.5 million liters of bioethanol

Table 4. Status for biofuels in Moldova

Fuel Type	2022–23 Use (liters)	Required Biofuel Blending (liters)
Diesel	757 million	36.6 million (biodiesel)
Gasoline	225 million	15.5 million (bioethanol)

Key barriers include:

a) Lack of refineries and blending infrastructure;
b) Absence of biofuel production facilities (traditional and advanced);
c) Low awareness across the value chain – from suppliers to end users.

Opportunity: With policy reform, stakeholder engagement, and infrastructure support (especially via FEZs), Moldova can build a viable domestic biofuel market and meet its 2030 climate obligations.

3.2. Biofuel Cost Analysis and Incentive Strategy to 2030

Moldova imports all fuel for transport due to the lack of domestic refineries. However, there is local bioethanol production capacity (e.g., Zernoff Company), with potential for blending at Giurgiulești and Constanța ports or in Free Economic Zones (FEZs).

Project consultations identified key stakeholder synergies:

a) Zernoff: Can produce 1st-gen bioethanol and possibly biodiesel from DDGS.
b) Rompetrol: Open to blending domestic and imported biofuels with conventional fuels in line with EU standards (RED II, FQD, DAFI).

Three strategic supply chain options were defined:

1. Domestic Production & Blending (Best Option): Biofuel production, storage, and blending inside Moldova, using FEZs like Giurgiulești.

2. Blending Abroad & Re-import: Production in Moldova, blending abroad (e.g., Constanța), then re-imported. Higher cost but feasible.
3. Full Import of Pre-Blended Fuels: Highest cost (+30%) but required in absence of local biodiesel infrastructure.

Currently, as per table 5, Moldova produces ~25.4 million liters/year of bioethanol – covering 74% of national demand (~34.3 million liters). Biodiesel supply is negligible, requiring imports to meet demand (~36.6 million liters/year).

Table 5. Biofuel cost analysis

Biofuel Type	**Domestic Supply**	**National Demand (liters)**
Bioethanol (Zernoff)	25.4 million liters	34.3 million liters
Biodiesel (DDGS)	<1% of demand	36.6 million liters

Future potential includes:

a) Advanced bioethanol from straw (double-counting eligible)
b) 1st-gen ethanol from sugar beet (not eligible)
c) Biodiesel from sunflower oil (1st-gen, not eligible) and UCO (double-counting eligible)

Cost considerations include:

a) Biomass feedstock price & availability
b) Technology readiness (TRL)
c) Blending, logistics, VAT, and import duties

Oil companies estimate fuel price increases of:

a) ~€0.20/liter for E5 gasoline (5% ethanol) and B7 diesel (7% biodiesel)

Stakeholders are ready to collaborate, with implementation timelines of 4–6 months once regulations are finalized. National law No. 10/2016 supports prioritizing local feedstock, especially for options 1 and 2.

3.3. Cost Analysis of Biofuel Supply Chains in Moldova

This section outlines cost estimates for various biofuel production pathways under national and EU-aligned scenarios. All figures reflect updated assumptions for 2024–2030.

3.3.1. Cereal-Based Bioethanol (1st Generation)

Produced locally by companies like **Zernoff**, corn-based ethanol is Moldova's most advanced domestic biofuel pathway. It covers up to 74% of national demand.

Component	**€/L**
Feedstock + Conversion	0.82
Taxes, blending, logistics	0.49
Total cost at pump (5% blend)	**1.31**
Gasoline pump price (2023–24)	1.30

➞ Slightly more expensive than pure gasoline; however, feasible with targeted incentives.

3.3.2. Cellulosic-Based Bioethanol (Advanced Biofuel)

No production exists in Moldova; imports from the EU are the only option. Supported by RED II for double counting, cellulosic ethanol is sustainable but expensive.

Total cost at pump (5% blend)	**1.84 €/L**
Gasoline pump price	1.30 €/L

➞Advanced bioethanol is 40–50% more costly due to high feedstock and conversion costs.

3.3.3. Sugar Beet-Based Bioethanol

While production in Moldova is absent, sugar beet remains a cost-effective feedstock if reintroduced.

Total cost at pump (8% blend)	**1.30–1.33 €/L**

➞ Comparable to conventional gasoline; viable if processing capacity is developed.

3.3.4 Biodiesel from DDGS (Advanced Biofuel)

Derived from residues of bioethanol production (Zernoff), DDGS-based biodiesel is a potential double-counting biofuel, though supply is limited (~1% of demand).

Component	**€/L**
Feedstock + Conversion	0.92
Taxes, blending, logistics	0.55
Total cost at pump (7% blend)	**1.12–1.47 €/L**
Diesel pump price (2023–24)	~1.06 €/L

➞ National production is minimal; imports remain essential to meet biodiesel targets.

Key Takeaways

a) Local cereal-based bioethanol is currently the most cost-effective and scalable option.
b) Advanced biofuels (e.g., straw ethanol, DDGS biodiesel) are sustainable but costly.
c) Strategic use of Free Economic Zones, targeted subsidies, and regional partnerships can reduce costs and strengthen supply chains.

3.3.5. Cost Analysis: Sunflower Oil-Based Biodiesel

Sunflower oil is abundant in Moldova but mainly used for food. According to EU STAR data, up to 20% could be diverted to biodiesel production without affecting food markets. Biodiesel could also be imported from neighboring countries.

Component	**€/L**
Feedstock + Conversion	0.67
Duties, blending, distribution	0.44
Total cost at pump (7% blend)	**1.10–1.27**
Diesel pump price (2023–2024)	~1.06

➞ Feasible option if national capacity is expanded or supplemented by regional imports.

3.4. Strategies to Reduce Biofuel Costs

Improving logistics and using Free Economic Zones (FEZ) – especially Giurgiulești Port – can lower costs by up to €0.20/L. The port's multimodal infrastructure, oil terminal, and storage capacity make it a prime location for biofuel handling and blending.

Key features of Giurgiulești Port:

a) Trimodal transport (road, rail, river);
b) Oil and grain terminals, 50,000-ton storage;
c) Customs-free operations under FEZ status.

Other active FEZs (e.g., Bălți) can host agro-energy and biofuel production investments, benefitting from:

a) VAT/excise exemptions;
b) 25-year guaranteed FEZ status;
c) Favorable export/import conditions.

4. CONCLUSION AND FINAL RECOMMENDATIONS

Moldova relies heavily on fuel imports, yet holds strong potential to develop biofuel production using local biomass (e.g., cereals, sunflower oil, DDGS). While the absence of refineries remains a constraint, interim blending can occur via Giurgiulești or Constanța ports.

Scaling national biofuel capacity could:

a) Reduce energy dependency;
b) Boost rural income and jobs;
c) Align with RED II and Moldova's Renewable Energy Law (10/2016).

Blending mandates and targeted investments will be key to unlocking this sector by 2030.

Short-Term Strategy (by 2030):

a) Blend national and imported biofuels at ports or in EU-based refineries.
b) Enforce compliance with RED II, FQD, ILUC.
c) Certify sustainability and blending quality via accredited labs and operators.

Long-Term Strategy (Post-2030):

a) Develop decentralized biofuel plants for cost-effective rural production.
b) Focus investments on:
    - Local biomass availability
    - Stakeholder capacity-building (farmers, companies, regulators)
    - Policy incentives for advanced biofuels
c) Monitor evolving trends: EV expansion, biofuel tech, commodity prices.

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