eISSN 2522-1566
ISSUE 3 (37), 2026

ECONOMICS AND INTERNATIONAL ECONOMIC RELATIONS

RECEIVED:
05 August 2026
ACCEPTED:
18 September 2026
RELEASED:
20 October 2026

CC BY 4.0

UDC 338.43:664:658.567.1(477)

DOI 10.26661/2522-1566/2026-3/37-01

CIRCULAR REDIRECTION OF PROTEIN FLOWS IN UKRAINE'S AGRI-FOOD SECTOR TOWARDS DEEPER-PROCESSED PRODUCTS

Dmytro Kurinskyi*
PhD in Management, Senior Research Fellow,
Sumy National Agrarian University,
Sumy, Ukraine
Advisor of Strategic Management Department,
Selkat Holding in Singapore,
Singapore, The Republic of Singapore
ORCID 0000-0001-9025-778X

** Corresponding author email: d.kurinskyi@snau.edu.ua*

Abstract. The study addresses the lack of a tool for comparing the economic result of deeper processing of sunflower and soybean meal with the opportunity cost of the existing export route and the cost of screening suitable feedstock. A material-and-protein flow model is proposed that combines the national balance identity, contractual and laboratory screening, product output, protein mass and a normalised route netback. Its management output is the identification of screening scale, break-even thresholds and margin cushions for rejecting economically fragile routes before full investment appraisal. The empirical base consists of FAS/Kyiv Post New balance estimates for MY 2024/25, treated as a coherent institutional dataset rather than official USDA statistics. Under the baseline coverage of 25% of exports, suitable feedstock equals 0.8988 million tonnes, product output 0.4458 million tonnes and protein in the product 0.2804 million tonnes; the combined incremental margin of the two routes equals USD 23.60 million. Break-even normalised product netbacks are USD 1,031 per tonne for the sunflower route and USD 959 per tonne for the soybean route, leaving cushions of only 6.3% and 4.1%. A 100-thousand-tonne product line requires actual processing of 7.4% of sunflower-meal exports or 7.2% of soybean-meal exports, while contractual and laboratory screening must cover 13.4% and 9.7% of the respective flows. Unchanged recorded domestic use is imposed as a feed-related constraint, whereas circularity requires separate verification of residual fractions, water, energy and effluents. The model supports pre-investment screening and pilot-route selection; it does not replace project-level techno-economic or investment appraisal.

Keywords: circular economy, protein flows, sunflower meal, soybean meal, protein balance, deep processing, export net back, feed security, Ukraine's food security, strategic management.
JEL Classification: M21, Q12, Q18.

INTRODUCTION

Ukraine generates substantial flows of sunflower and soybean meal that follow established feed and export routes. While exports support foreign exchange earnings and maintain the utilisation of the oilseed crushing industry, they also reinforce specialisation in a product with relatively limited value added. Redirecting these flows towards protein ingredients may increase the

technological sophistication of exports; however, this opportunity cannot be inferred directly from the physical volume of meal produced.

Under Article 9 of the Law of Ukraine "On Waste Management", a substance may be recognised as a by-product only if it simultaneously satisfies the conditions of a defined subsequent use, suitability for further use without processing beyond normal industrial practice, generation as an integral part of the production process, and compliance with safety requirements [1]. Commercial meal with stable market demand generally satisfies these criteria; however, by-product status should not be assumed automatically for every batch or residual fraction.

The new EU framework for a competitive and sustainable bioeconomy shifts the focus from the general concept of cascading biomass use towards industrial scale-up, market development for bio-based products, investment mobilisation and competitiveness [2]. For Ukraine, deeper processing should therefore be assessed simultaneously as a material pathway, a protein balance, a product specification and an investment project. An increase in the number of processing stages alone does not demonstrate either circularity or economic feasibility.

LITERATURE REVIEW

Studies on the circular agri-food economy associate value enhancement of secondary material streams with material traceability and market utilisation [3–5]. Scientific and technical research confirms the feasibility of protein extraction from oilseed meals, although the outcome depends on feedstock composition, protein denaturation, fibre content, phenolic compounds, solubility and purification conditions [6–10]. Ivanova et al. achieved protein recovery exceeding 50% from sunflower meal under optimised processing conditions [8], whereas the soybean route demonstrates substantial sensitivity of product yield and composition to the applied pre-treatment method [9]. Kaur and Ghoshal comprehensively reviewed the composition, extraction methods and functional properties of sunflower protein isolates [11].

Product mass yield is not equivalent to protein recovery. A comprehensive assessment requires simultaneous consideration of protein concentration in the original meal, protein content in the concentrate and the amount of protein retained in residual fractions. According to Codex, soy protein concentrate is defined as a product containing not less than 65% and less than 90% protein on a dry matter basis [12]. Moreover, protein quality cannot be evaluated solely by protein quantity. Quantitative evidence demonstrates considerable variation in DIAAS and PDCAAS values among soy protein products depending on processing technology and operating conditions [13].

Economic evaluation of biorefining requires an integrated material, energy and financial balance. Techno-economic assessments of integrated biorefinery systems incorporate capital expenditure, utilities, plant utilisation, production scale and sensitivity analysis [14]. Consequently, a margin-based assessment at the national flow level can serve as a pre-screening tool but cannot substitute for project-level NPV, IRR or minimum product selling price analysis. Studies by Sitnicki, Kurinskyi and co-authors associate the competitiveness of the agricultural sector with cluster coordination, adaptive business models and the organisation of export supply chains [15–17]. Research on the digitalisation of circular business models in the agro-industrial sector highlights the role of digital auditing of resource flows, product traceability, by-product valorisation and platform-based cooperation, while methodological approaches to enterprise digital transformation emphasise infrastructure, managerial competencies, integration capability, security and organisational resilience [18–19]. For deeper processing, these findings imply that the technological pathway should be evaluated jointly with feedstock contracting, market absorption capacity and the opportunity cost of the existing export route.

Identification of the Research Gap. Existing studies have not developed a transparent model that simultaneously: reconstructs the complete national material balance for oilseed meals; distinguishes the volume covered by contractual procurement from the quantity of technically suitable feedstock; quantifies protein at both the input and concentrate stages; deducts the opportunity cost of

the existing export route; incorporates the costs of screening non-compliant batches; constrains production by processing capacity and confirmed offtake; and distinguishes the accounting requirement of maintaining domestic utilisation from a comprehensive assessment of feed security.

PAPER OBJECTIVE

The objective of this study is to assess the material, protein and preliminary trade-value potential of redirecting part of Ukraine's export flows of sunflower and soybean meal towards higher-value processed products while maintaining the recorded level of domestic utilisation.

METHODOLOGY

Research methods. The study employs material flow analysis (MFA), the material balance approach, scenario modelling, protein balance analysis, margin analysis, break-even analysis, and normative content analysis. The unit of analysis is defined as the combination of meal type – export pathway – contractual procurement scenario – alternative value-added product.

Data sources. The material balance was constructed using the FAS/Kyiv Oilseeds and Products Annual report for Ukraine (Report UP2025-0008), specifically the Post New estimates for the 2024/25 marketing year [20]. As the report explicitly identifies these values as estimates and assumptions valid at the time of publication, they are treated in this study as secondary institutional material balance data. For soybean meal, the Post New estimates differ substantially from the USDA Official figures. Consequently, the soybean scenario represents the most sensitive case in the analysis, since both the export flow (E = 2.3 million tonnes) and the accounting constraint for domestic utilisation (D = 0.15 million tonnes) are derived from the least stable component of the material balance.

Table 1

Status of Model Data and Parameters

Category	Parameters	Status	Interpretation Rule
2024/25 Marketing Year Material Balance	Stocks, production, imports, domestic utilisation, exports	FAS/Kyiv Post New; secondary estimates	Used as a consistent material balance framework rather than as official USDA statistics
Technological Parameters	λ, product yield, protein content	Scenario values derived from the literature	Not intended to represent normative values for Ukrainian processing facilities
Commercial Parameters	Netbacks, processing costs, screening costs, residual value	Author-defined scenarios	Compared at the same geographical location and contractual reference point
Feed Constraint	Domestic utilisation and ending stocks	Exogenous accounting constraint	Does not imply unchanged prices, nutritional quality, or livestock production costs
Model Outputs	Protein concentrate, protein mass, margin, break-even point	Model-derived estimates	Do not represent gross value added (GVA), profit, NPV, or market demand forecasts

Source: Developed by the author based on [6–17; 20].

Analytical Framework. The complete national material balance for meal stream *i* distinguishes production from total supply:

$$B_i + P_i + I_i = D_i + E_i + S_i^{end}, \qquad (1)$$

where *B* denotes beginning stocks; *P* – production; *I* – imports; *D* – domestic utilisation; *E* – exports; and *S^end* – ending stocks. As the FAS/Kyiv balance does not identify a separate category for deeper processing, the scenario is modelled as a reallocation of part of the export route while keeping *D* and *S^end* unchanged.

$$Q_{i,s}^{screen} = sE_i;\ Q_{i,s}^{red} = \lambda_i Q_{i,s}^{screen};\ E_{i,s}^{after} = E_i - Q_{i,s}^{red}. \qquad (2)$$

The share *s* represents the proportion of the export flow covered by contractual procurement and quality screening. Only the technically suitable fraction, λ, is redirected to the alternative processing route, whereas the unsuitable fraction remains on the baseline export pathway. Product output is determined as:

$$Q_{i,s}^{conc} = y_i Q_{i,s}^{red}. \qquad (3)$$

The protein balance accounts for protein mass in the suitable feedstock and in the final product:

$$Prot_i^{in} = Q_{i,s}^{red} c_i^{meal};\ Prot_i^{conc} = Q_{i,s}^{conc} c_i^{conc};\ \eta_i^{prot} = \frac{Prot_i^{conc}}{Prot_i^{in}}. \qquad (4)$$

The difference between *Prot^in* and *Prot^conc* is not interpreted as a protein loss, since part of the protein may remain in solid or liquid co-products and therefore requires separate quantification. The scenario-based balance is performed on a mass basis; an industrial process would additionally require complete balances for dry matter, water, solvents and wastewater streams.

To ensure price comparability, the market price of the protein concentrate is converted into a normalised ex-plant netback:

$$N_i^{conc} = P_i^{market} - L_i^{out} - C_i^{pack} - C_i^{cert} - C_i^{trade}. \qquad (5)$$

The scenario values of *N^conc* reported in the tables do not represent observed market quotations. Instead, they define a comparable netback after logistics, packaging, insurance, certification and market access costs. The incremental margin also incorporates the cost of screening the entire volume covered by contractual procurement:

$$\Delta M_{i,s} = Q_{i,s}^{red}\left[\left(N_i^{conc} y_i + R_i - C_i^{proc}\right) - N_i^{meal}\right] - Q_{i,s}^{screen} C_i^{screen}. \qquad (6)$$

The physical scenario should not be interpreted as a market forecast. Actual production is constrained by installed processing capacity (*K*) and confirmed market absorption or offtake (*M*):

$$Q_{i,s}^{real} = \min\left(Q_{i,s}^{conc}, K_i, M_i\right). \qquad (7)$$

Scenario Assumptions and Study Boundaries. The baseline protein content was assumed to be 36% for sunflower meal and 46% for soybean meal. The corresponding products were assumed to

contain 60% protein for the sunflower protein-enriched concentrate and 65% protein for the soy protein concentrate, with the latter corresponding to the lower Codex threshold for SPC [12] rather than to the specification of any particular manufacturer. The scenario prices of USD 1,100 per tonne for the sunflower product and USD 1,000 per tonne for the soy product represent normalised netbacks, not observed market prices.

Study limitations. The model does not incorporate capital expenditure (CAPEX), the weighted average cost of capital (WACC), taxation, working capital requirements, construction time, equipment degradation, capacity underutilisation, water treatment infrastructure, or waste disposal costs. It also does not evaluate changes in domestic meal prices, feed substitution effects, the nutritional requirements of individual livestock species, or the impact on livestock production costs. Maintaining *D* unchanged constitutes an accounting constraint rather than evidence of feed security. Furthermore, the hard modelling constraint applied to the soybean pathway is based on the relatively uncertain Post New estimate. Consequently, the results for this material flow require separate verification using trade, production and feed statistics.

RESULT AND DISCUSSION

National Material Balance

The structure of meal supply and utilisation is presented in Table 2.

Table 2

Material Balance of Sunflower and Soybean Meal Based on FAS/Kyiv Post New Estimates, 2024/25 Marketing Year (million tonnes)

Indicator	Sunflower Meal	Soybean Meal
Beginning stocks	0,158	0,151
Production	5,204	2,372
Imports	0,001	0,002
Total supply	5,363	2,525
Domestic utilisation	1,800	0,150
Exports	3,400	2,300
Ending stocks	0,163	0,075
Balance identity check	5,363 = 5,363	2,525 = 2,525

Source: Compiled from FAS/Kyiv [20]. All balance values are reported in million tonnes. The data represent Post New expert estimates and do not constitute official USDA statistics.

For sunflower meal, total supply is distributed relatively evenly among exports, domestic utilisation, and ending stocks. For soybean meal, the Post New balance projects exports of 2.3 million tonnes and domestic utilisation of 0.15 million tonnes.

The substantial discrepancy relative to the USDA Official estimates requires increased caution in interpreting the results. Accordingly, all calculations are based on the internally consistent Post New dataset, while the precise size of the national reserve requires further verification.

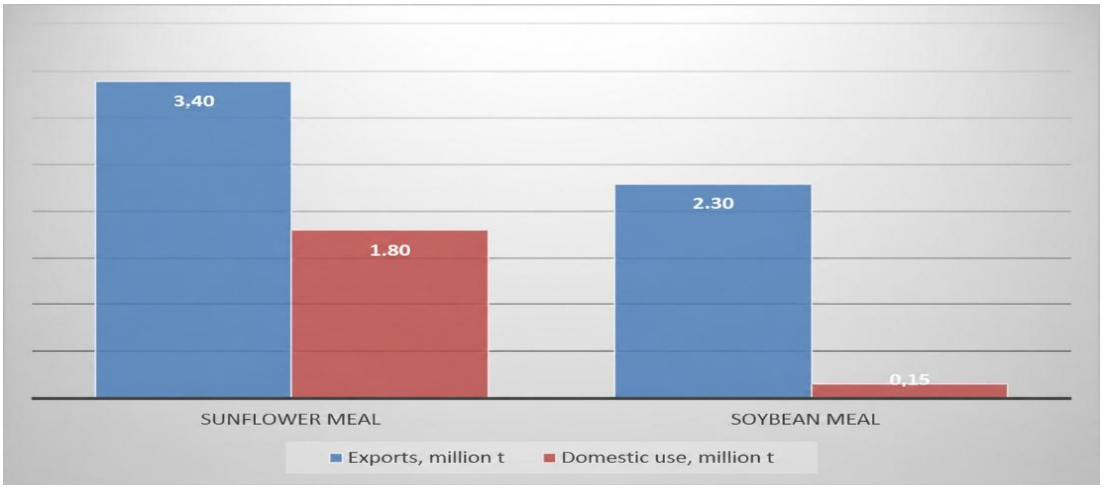


Figure 1. Exports and Domestic Utilisation of Oilseed Meals Based on FAS/Kyiv Post New Estimates

Source: Constructed by the author based on [20]. All values in the figure are reported in million tonnes.

Baseline Route Profile. The technological and commercial assumptions for the baseline routes are presented in Table 3.

Table 3

Scenario Parameters of the Baseline Routes

Parameter	Sunflower Route	Soybean Route	Interpretation
λ	0.55	0.75	Share of the screened flow that meets the technological requirements
y, t/t	0.40	0.60	Mass yield of the product from suitable feedstock
Protein content in meal	36%	46%	Scenario composition of the initial feedstock
Protein content in product	60%	65%	Product specification; for SPC – the minimum Codex threshold
Nmeal, USD/t	215	355	Normalised netback of the baseline export route
Nconc, USD/t	1,100	1,000	Scenario-based product netback at the same contractual reference point
Cproc, USD/t of suitable feedstock	230	250	Additional process operating costs
Cscreen, USD/t of screened flow	4	4	Inspection, sorting, and laboratory testing
R, USD/t of suitable feedstock	40	35	Scenario value of the safe utilisation of residual fractions

Source: The exact values represent author-defined scenarios; the technological and product-related ranges were established based on [6–13]. Nmeal was calibrated using the dynamics of domestic EXW prices reported by FAS/Kyiv with reference to APK-Inform data [20, Fig. 12]: approximately UAH 6.3–11.5 thousand per tonne for sunflower meal and UAH 16.4–22.2 thousand per tonne for soybean meal between January 2024 and March 2025. The netbacks of USD 215 and USD 355 per tonne are conservative scenario values normalised to a common contractual reference point. They do not reproduce any specific monthly quotation and should be replaced with actual company-level contract data.

eISSN 2522-1566
ISSUE 3 (37), 2026

Protein Balance under the Baseline Scenario. Under the scenario with s = 25%, contractual screening covers 0.85 million tonnes of the sunflower export flow and 0.575 million tonnes of the soybean export flow. After applying λ, the volume of suitable feedstock amounts to 0.4675 and 0.4313 million tonnes, respectively. The protein balance demonstrates that concentrate mass alone does not adequately characterise the efficiency of protein redirection.

Table 4

Material and Protein Balance under 25% Coverage of Export Flows

Flow	Covered by Screening, million t	Suitable Feedstock, million t	Product, million t	Protein Input, million t	Protein in Product, million t	Protein Recovery, %
Sunflower	0.8500	0.4675	0.1870	0.1683	0.1122	66.7
Soybean	0.5750	0.4312	0.2587	0.1984	0.1682	84.8
Total	1.4250	0.8987	0.4457	0.3667	0.2804	76.5

Source: Calculated by the author. The difference between protein input and protein in the final product remains in co-product fractions or process losses and therefore requires measurement at the pilot-line stage.

The sunflower route concentrates 0.1122 million tonnes of protein from 0.1683 million tonnes contained in the suitable feedstock, corresponding to 66.7%. For the soybean route, 0.1682 million tonnes of protein in the product are compared with 0.1984 million tonnes at the input, resulting in a recovery rate of 84.8%. These values provide a scenario-based consistency check of y, cmeal and cconc. Industrial validation requires batch-level material and protein balances.

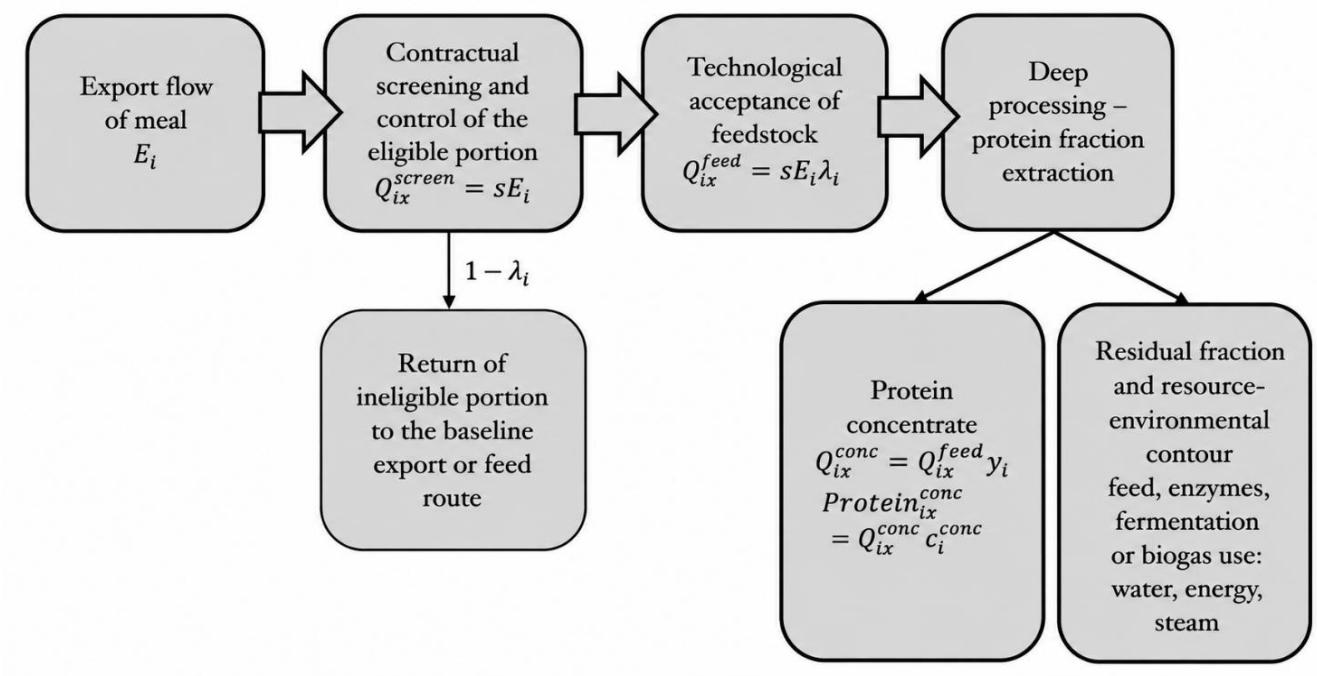


Figure 2. Redirection Pathway with Separate Accounting for Protein, Residual Fractions, and Resources

Source: Developed by the author.

Note. Circularity status requires closure of the material and protein balances, documentation of the utilisation of residual fractions, and measurement of water, energy, and environmental parameters.

Export Flow Coverage Scenarios. The physical, protein, and margin results are presented in Table 5.

Table 5

Physical, Protein, and Margin Results under Alternative Scenarios

Screening Share	Flow	Covered by Screening, million t	Suitable Feedstock, million t	Product, million t	Protein in Product, million t	Margin, USD million
10%	Sunflower	0.3400	0.1870	0.0748	0.0449	5.19
10%	Soybean	0.2300	0.1725	0.1035	0.0673	4.25
10%	Total	0.5700	0.3595	0.1783	0.1122	9.44
25%	Sunflower	0.8500	0.4675	0.1870	0.1122	12.96
25%	Soybean	0.5750	0.4312	0.2587	0.1682	10.64
25%	Total	1.4250	0.8987	0.4457	0.2804	23.60
50%	Sunflower	1.7000	0.9350	0.3740	0.2244	25.93
50%	Soybean	1.1500	0.8625	0.5175	0.3364	21.27
50%	Total	2.8500	1.7975	0.8915	0.5608	47.20

Source: Calculated by the author. The margin includes the forgone netback from meal exports and the screening costs for the entire flow covered by screening.

Export Flow Coverage Scenarios. Under the 10%, 25%, and 50% scenarios, total product output amounts to 0.1783, 0.4458, and 0.8915 million tonnes, respectively, while the corresponding protein content in the product reaches 0.1122, 0.2804, and 0.5608 million tonnes. The linear increase in margin is a characteristic of the baseline demonstration, in which no allowance is made for price reductions resulting from increased supply, processing capacity constraints, or the limits imposed by certified offtake. The 50% scenario defines the arithmetic upper limit of the physical flow; it does not assess the capacity of the actual market.

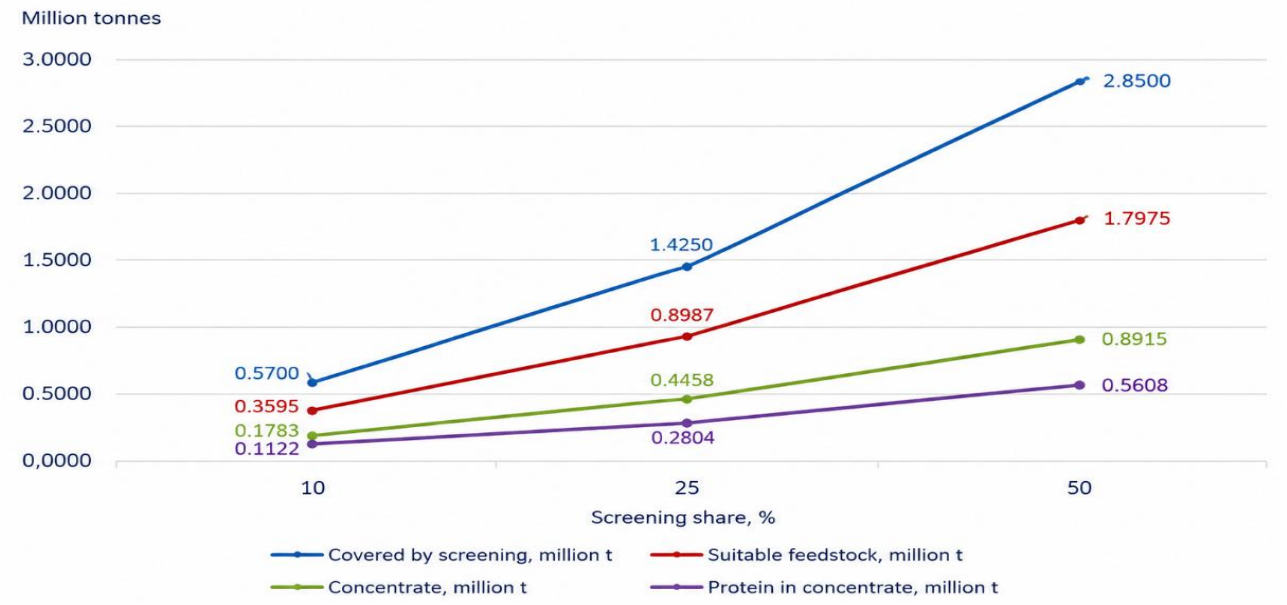


Figure 3. Material and Protein Results under Export Flow Coverage Scenarios

Source: Calculated by the author.

Capacity Scaling and Market Uptake. For the first industrial facility, a distinction is made between the share of the export flow covered by screening and the share that is actually directed to processing. Feedstock found to be unsuitable after screening remains on the original export route. Capacity estimation does not imply guaranteed market sales; before an investment decision is made, the processed volume is constrained by the contracted offtake, M, as defined in Equation (7).

Table 6

Capacity Equivalents Expressed as Shares of the Export Flow

Capacity, thousand t/year	Sunflower: Suitable Feedstock, thousand t	Export Flow Actually Processed, %	Export Flow Covered by Screening, %	Soybean: Suitable Feedstock, thousand t	Export Flow Actually Processed, %	Export Flow Covered by Screening, %
25	62.5	1.8	3.3	41.7	1.8	2.4
50	125.0	3.7	6.7	83.3	3.6	4.8
100	250.0	7.4	13.4	166.7	7.2	9.7

Source: Calculated by the author using the baseline values of λ and y. Export flow covered by screening = suitable feedstock / (λ × exports).

A production line with a capacity of 100 thousand tonnes of product requires 250 thousand tonnes of suitable sunflower meal or 166.7 thousand tonnes of suitable soybean meal. The actual volume directed to processing corresponds to 7.4% and 7.2% of the respective export flows, whereas laboratory and contractual screening covers 13.4% and 9.7% of those flows. The workload imposed on the screening system is determined by the broader screening scope, while the processing line operates only with suitable feedstock.

Break-even Points and Parametric Uncertainty. Taking screening costs into account, the break-even product netback is determined as:

$$N_i^{be} = (N_i^{meal} + C_i^{proc} - R_i + C_i^{screen}/\lambda_i) / y_i. \qquad (8)$$

For the sunflower route, Nbe equals USD 1,031/t, whereas for the soybean route it equals USD 959/t. The margin relative to the scenario product netback is only 6.3% and 4.1%, respectively. This represents the central screening result of the analysis: the baseline route remains above the break-even threshold, yet even a small change in the product price, processing costs, or screening costs eliminates the positive margin. A full TEA is required for an investment decision; however, the economic vulnerability has already been quantified.

The lower scenario sets produce a negative margin for both processing routes. The upper scenario sets demonstrate substantial potential under simultaneously favourable assumptions regarding feedstock suitability, product yield, product quality, costs, and netback. The scenario range does not represent a statistical confidence interval. Rather, it defines combinations of parameters that must be validated through a pilot production line and an offtake contract before proceeding to a full techno-economic model.

Table 7

Uncertainty Range under the Scenario of 25% Export Flow Coverage

Flow	Scenario	λ / y	Protein: Meal / Product	Nconc / Cproc / R / Cscreen, USD/t	Protein Recovery, %	Margin per tonne of Suitable Feedstock, USD	Margin, USD million
Sunflower	Lower	0.40/0.32	36%/58%	900/270/25/6	51.6	-187.0	-63.58
Sunflower	Baseline	0.55/0.40	36%/60%	1100/230/40/4	66.7	27.7	12.96
Sunflower	Upper	0.70/0.50	38%/62%	1250/210/55/3	81.6	250.7	149.17
Soybean	Lower	0.60/0.50	44%/65%	850/300/ 20/5	73.9	-218.3	-75.32
Soybean	Baseline	0.75/0.60	46%/ 65%	1000/250/35/4	84.8	24.7	10.64
Soybean	Upper	0.85/0.65	48%/ 70%	1150/220/50/3	94.8	219.0	107.02

Source: Calculated by the author. All numerical parameter values have scenario status.

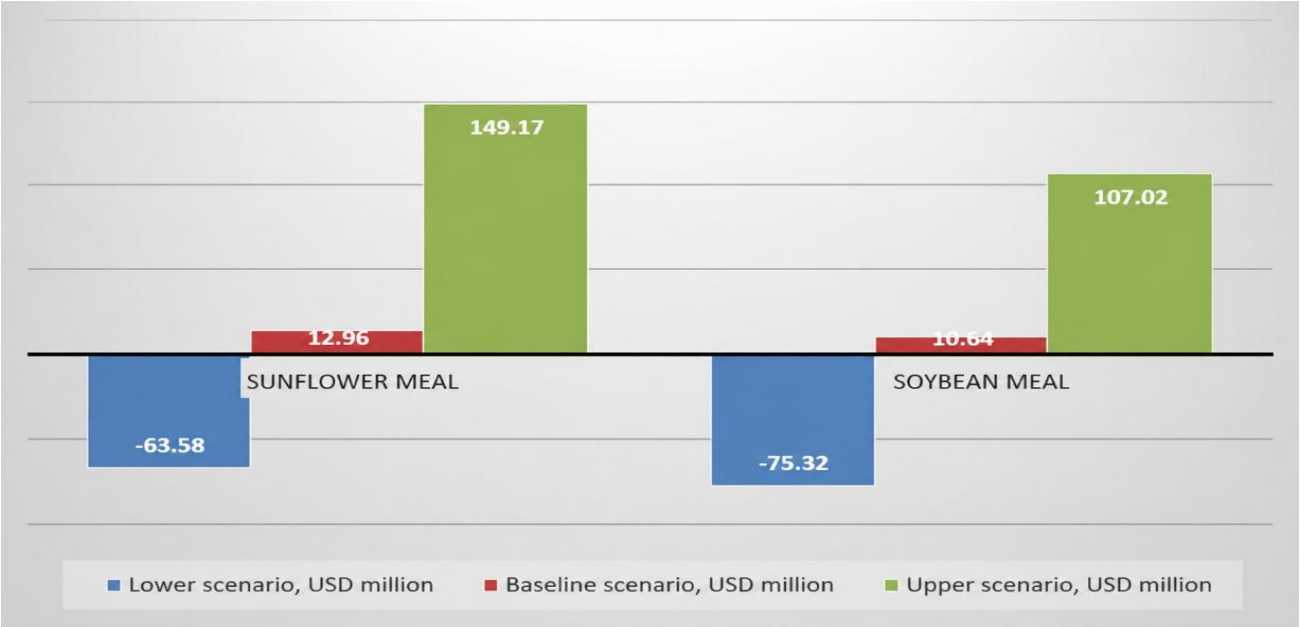


Figure 4. Lower, Baseline, and Upper Scenario Estimates of the Incremental Margin under 25% Export Flow Coverage

Source: Calculated by the author.

Strategic, Regulatory, and Circularity Conditions. Maintaining the accounting level of domestic utilisation unchanged protects the baseline physical flow but does not demonstrate feed security [21]. The model does not account for domestic market prices, the nutritional equivalence of feeds, the requirements of poultry, pigs, and cattle, possible substitution by alternative protein ingredients, or producers' behavioural responses. The estimate of domestic soybean meal utilisation reported in the FAS/Kyiv Post New balance is itself a source of uncertainty. A management indicator should

therefore incorporate the volume of domestic utilisation (D), feed protein prices, nutritional quality, and feed ration costs.

The regulatory pathway depends on the intended use of the product. Feed, food, and functional protein concentrates are subject to different specifications and requirements regarding allergenicity, solvent residues, microbiological quality, and history of use. Regulation (EU) 2015/2283 does not automatically classify every concentrate as a novel food but requires assessment of the specific ingredient and production process [22]. For soy protein concentrate, the baseline compositional reference is provided by the Codex standard [12]. For sunflower protein products, a contractual product specification is required, as no equivalent unified standard is applied within the present model.

Circularity is not presented as an achieved outcome [23]. The scenario value of R tests the economic role of residual fractions but does not confirm their actual utilisation. Verification requires closure of the dry matter and protein balances, accounting for water and energy use, monitoring of COD and BOD, documented utilisation pathways for each residual fraction, and assessment of primary resource substitution.

The transition from the national material balance to an investment decision comprises eight sequential verification stages: confirmation of the material balance identity; assessment of batch suitability and screening costs; batch-level protein balance; product specification and normalised netback; evaluation of feed-related effects; material and energy verification of circularity; a full TEA incorporating CAPEX, WACC, NPV, IRR, DSCR, and DPP; and phased capacity expansion within the limits of confirmed offtake and available infrastructure.

Interpretation of the Results. The material–protein model distinguishes between product mass and protein mass in the feedstock, in the concentrate, and potentially in the residual fractions. Protein quality remains beyond the scope of the calculations. Food applications require assessment of the amino acid profile, digestibility, and DIAAS/PDCAAS, whereas feed applications require evaluation of species-specific nutritional value and anti-nutritional factors.

Accounting for screening costs incorporates the economic consequences of identifying unsuitable batches. For a production line with a capacity of 100 thousand tonnes of sunflower protein product, approximately 454.5 thousand tonnes of the export flow must be screened, although only 250 thousand tonnes enter processing. This difference determines the required capacity for laboratory testing, sampling, traceability, segregated storage, and contractual procedures for returning unsuitable batches.

Comparison with Previous Studies. Previous technological studies [6–10] have primarily evaluated protein recovery, composition, and functional properties at the laboratory or pilot scale. Circular bioeconomy approaches [2–5] require traceability of all material fractions, whereas techno-economic models [14] additionally incorporate capital investment, utilities, plant utilisation, and production scale. The proposed model integrates these research directions at the level of the national material flow by incorporating the opportunity cost of exports, a separate protein balance, and screening costs.

Scientific Novelty. The proposed model simultaneously distinguishes the volume covered by contractual screening, technically suitable feedstock, product mass yield, and protein recovery. The economic result is defined as the incremental margin after deducting the baseline export netback and the cost of screening the entire selected flow. This framework eliminates double counting and makes the break-even point a verifiable result.

The study is a way of developing the provisions of the previous series of publications regarding the development of innovative potential and strategic flexibility of enterprises [24], managerial prospects for the development of the agricultural industry in the context of European integration [25], the development of methodological foundations for measuring the commercial potential of new products of the agro-industrial sector using the theory of fuzzy sets [26], as well as the search for

effective ways to increase the level of strategic flexibility for stable agro-industrial enterprises of Ukraine and countries with economies in transition [27].

Practical Significance. A successful processing route may increase export sophistication and technological autonomy while simultaneously increasing dependence on water, energy, processing equipment, certification, and a specialised ingredients market. Public policy should support the sequence of material balance – pilot production – product qualification – offtake – TEA – monitoring of feed and food security effects.

The relationship with food security encompasses livestock resilience, the availability of food protein, export revenues, market diversification, and the ability of the processing system to respond to external shocks. Empirical evaluation of these channels will become possible after data from the demonstration line and the domestic feed protein market become available.

CONCLUSION

The proposed model eliminates double counting between the existing export route and the product of deeper processing, distinguishes the volume covered by contractual screening from the volume of technically suitable feedstock, and makes the break-even point a verifiable criterion for preliminary project screening. Its managerial value lies in the ability to reject processing routes with an insufficient margin before incurring the costs of a full techno-economic and investment appraisal, while also determining the required scale of contractual and laboratory infrastructure.

The FAS/Kyiv Post New material balance for the 2024/25 marketing year represents an internally consistent set of secondary estimates. The complete balance identity comprises beginning stocks, production, imports, domestic utilisation, exports, and ending stocks. The scenario shares of 10%, 25%, and 50% define the proportion of exports covered by contractual screening; only the suitable fraction, λ, is redirected to deeper processing, whereas the remaining volume follows the baseline export route.

Under the baseline 25% scenario, suitable feedstock amounts to 0.8988 million tonnes, product output reaches 0.4458 million tonnes, and protein in the final product totals 0.2804 million tonnes. The protein recovery rate equals 66.7% for the sunflower route and 84.8% for the soybean route. A production line with a capacity of 100 thousand tonnes of product actually processes 7.4% of sunflower meal exports or 7.2% of soybean meal exports, whereas 13.4% and 9.7% of the respective export flows must be covered by screening. This difference determines the costs associated with laboratory and contractual infrastructure.

Normalising prices to a common contractual reference point and incorporating screening costs yields an incremental margin of USD 12.96 million for the sunflower route and USD 10.64 million for the soybean route under the 25% export coverage scenario. The corresponding break-even product netbacks are USD 1,031/t and USD 959/t, while the margins relative to the scenario netbacks equal 6.3% and 4.1%, respectively. This margin provides a quantitative test of economic vulnerability: even a small deterioration in product prices or costs shifts the baseline scenario into the negative range. The lower scenario sets confirm this conclusion.

Maintaining the accounting level of domestic utilisation unchanged remains a model-based feed constraint. A comprehensive assessment requires information on prices, nutritional quality, feed substitution, and livestock production costs, while the soybean route is additionally affected by the uncertainty associated with the Post New estimates. Circularity status requires verification of material and protein balances, utilisation of residual fractions, specific water and energy consumption, wastewater loading, and substitution of primary resources. The model is suitable for screening pilot processing routes, whereas a final investment decision requires a process-based TEA, market validation, and evaluation using NPV, IRR, DSCR, and DPP.

REFERENCES

Verkhovna Rada of Ukraine (2022). *On waste management* : Law No. 2320-IX. https://zakon.rada.gov.ua/go/2320-20

European Commission (2025). *A strategic framework for a competitive and sustainable EU bioeconomy (COM(2025) 960 final)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0960

Dovgal, O., & Potryvaieva, N. (2024). Practical study of the implementation of circular economy at agricultural enterprises of Ukraine. *Ukrainian Black Sea Region Agrarian Science*, 28 (1), 9–18. https://doi.org/10.56407/bs.agrarian/1.2024.09

Toop, T. A., et al. (2017). AgroCycle–developing a circular economy in agriculture. *Energy Procedia*, 123, 76–80. https://doi.org/10.1016/j.egypro.2017.07.269

Ubando, A. T., Felix, C. B., & Chen, W.-H. (2020). Biorefineries in circular bioeconomy : A comprehensive review. *Bioresource Technology*, 299, 122585. https://doi.org/10.1016/j.biortech.2019.122585

Singh, R., et al. (2022). Protein for human consumption from oilseed cakes : A review. *Frontiers in Sustainable Food Systems*, 6, 856401. https://doi.org/10.3389/fsufs.2022.856401

Hadidi, M., Tan, C., Assadpour, E., & Jafari, S. M. (2024). Oilseed meal proteins : From novel extraction methods to nanocarriers of bioactive compounds. *Food Chemistry*, 438, 137971. https://doi.org/10.1016/j.foodchem.2023.137971

Ivanova, P., Chalova, V., Koleva, L., Pishtiyski, I., & Perifanova-Nemska, M. (2012). Optimization of protein extraction from sunflower meal produced in Bulgaria. *Bulgarian Journal of Agricultural Science*, 18 (2), 153–160. https://www.agrojournal.org/18/02-02-12.pdf

Wang, H., Johnson, L. A., & Wang, T. (2004). Preparation of soy protein concentrate and isolate from extruded-expelled soybean meals. *Journal of the American Oil Chemists' Society*, 81, 713–717. https://doi.org/10.1007/s11746-004-966-8

Becze, A., et al. (2025). Optimization of protein extraction from sunflower meal using Taguchi design and regression modeling for human nutrition applications. *Foods*, 14 (14), 2415. https://doi.org/10.3390/foods14142415

Kaur, R., & Ghoshal, G. (2022). Sunflower protein isolates–composition, extraction and functional properties. *Advances in Colloid and Interface Science*, 306, 102725. https://doi.org/10.1016/j.cis.2022.102725

Codex Alimentarius Commission (1989, amended 2019 and 2022). *Standard for soy protein products (CXS 175-1989)*. https://www.fao.org/fao-who-codexalimentarius/codex-texts/standards/en

van den Berg, L. A., Mes, J. J., Mensink, M., & Wanders, A. J. (2022). Protein quality of soy and the effect of processing : A quantitative review. *Frontiers in Nutrition*, 9, 1004754. https://doi.org/10.3389/fnut.2022.1004754

Rosentrater, K. A., & Zhang, W. (2021). Techno-economic analysis of integrating soybean biorefinery products into corn-based ethanol fermentation operations. *Fermentation*, 7 (2), 82. https://doi.org/10.3390/fermentation7020082

Sitnicki, M., Kurinskyi, D., Pimenowa, O., Wasilewski, M., & Wasilewska, N. (2024). Strategic formation of agricultural market clusters in Ukraine : Emerging as a global player. *Sustainability*, 16(21), 9430. https://doi.org/10.3390/su16219430

Sitnicka, K., & Serhiienko, R. (2025). Business Adaptation to Extreme Conditions : Analysis of Business Shocks in the Context of the War in Ukraine. *SocioEconomic Challenges*, 9 (4), 216–255. https://doi.org/10.61093/sec.9(4).216-255.2025

Sitnicki, M. W., & Kurinskyi, D. O. (2022). Signing of the tripartite grain agreement as a solution to the organizational and management problems of Ukrainian agricultural enterprises. *Bulletin of Taras Shevchenko National University of Kyiv. Economics*, 4 (221), 58–63. https://doi.org/10.17721/1728-2667.2022/221-4/8

Kurinskyi, D. (2026). Circular redirection of protein flows in Ukraine's agri-food sector towards deeper-processed products. Management and Entrepreneurship: Trends of Development, 3(37), 12-28. https://doi.org/10.26661/2522-1566/2026-3/37-01

Pereguda, Y. A. (2026). Digitalisation as a driver for the implementation of circular business models in the agro-industrial complex. *Bulletin of Sumy National Agrarian University. Series "Economics and Management"*, 2 (106), 161–169. https://doi.org/10.32782/bsnau.D2026.2.24

Pereguda, Y., & Biloshkurska, N. (2026). Digital transformation as a strategic imperative for the development of innovative entrepreneurship in Ukraine in the context of international economic cooperation. *Social Development : Economic and Legal Issues*, 15. https://doi.org/10.70651/3083-6018/2026.3.19

USDA Foreign Agricultural Service (2025). *Oilseeds and products annual : Ukraine (Report UP2025-0008)*. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds+and+Products+Annual_Kyiv_Ukraine_UP2025-0008

Cabinet of Ministers of Ukraine (2024, current version January 6, 2026). *On approval of the Food Security Strategy of Ukraine until 2027 and the operational action plan for its implementation*: Order No. 684-r. https://zakon.rada.gov.ua/go/684-2024-%D1%80

European Parliament and Council (2015). Regulation (EU) 2015/2283 of 25 November 2015 on novel foods. *Official Journal of the European Union*, L 327, 1–22. https://eur-lex.europa.eu/eli/reg/2015/2283/oj/eng

Cabinet of Ministers of Ukraine (2024). *On approval of the National Waste Management Plan until 2033 and repeal of certain acts* : Order No. 1353-r. https://zakon.rada.gov.ua/go/1353-2024-%D1%80

Sitnicki, M.W. (2007). The impact of innovation potential on the strategic flexibility of an enterprise. *Statistics of Ukraine*, 1, 43-47.

Sitnicki, M.W., & Kurinskyi, D. O. (2022). Managerial perspectives of the development of the domestic agricultural industry in the conditions of Ukraine's status as a candidate for membership of the European Union. *Efektyvna Ekonomika*, 8. https://doi.org/10.32702/2307-2105.2022.8.14

Sitnicki, M., Balan, V., Tymchenko, I., Sviatnenko, V., Sychova, A. (2021). Measuring the commercial potential of new product ideas using fuzzy set theory. *Innovative Marketing*, 17 (2), 149–163. https://doi.org/10.21511/im.17(2).2021.14

Sitnicki, M.W., Wasilewska, N., Balan, V., Tymchenko, I., Wasilewski, M., Pimenowa, O., & Sitnicka, S. (2026). Enhancing Strategic Flexibility for Sustainable Agro-Industrial Enterprises in Transition Economies : a Fuzzy Multicriteria Approach. *Technological and Economic Development of Economy*, 32 (3), 996–1023. https://doi.org/10.3846/tede.2026.25543

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

1. Верховна Рада України. *Про управління відходами*. Закон України. № 2320-IX. 2022. URL: https://zakon.rada.gov.ua/go/2320-20

2. European Commission. *A strategic framework for a competitive and sustainable EU bioeconomy (COM(2025) 960 final)*. 2025. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0960

3. Dovgal O., Potryvaieva N. Practical study of the implementation of circular economy at agricultural enterprises of Ukraine. *Вісник Аграрної Науки Причорномор'я*. 2024. № 28 (1). С. 9–18. URL: https://doi.org/10.56407/bs.agrarian/1.2024.09

4. Toop T. A. et al. AgroCycle–developing a circular economy in agriculture. *Energy Procedia*. 2017. № 123. Pp. 76–80. URL: https://doi.org/10.1016/j.egypro.2017.07.269

5. Ubando A. T., Felix C. B., Chen W.-H. Biorefineries in circular bioeconomy : A comprehensive review. *Bioresource Technology*. 2020. № 299. URL: https://doi.org/10.1016/j.biortech.2019.122585

6. Singh R. et al. Protein for human consumption from oilseed cakes : A review. *Frontiers in Sustainable Food Systems*. 2022. № 6. URL: https://doi.org/10.3389/fsufs.2022.856401

7. Hadidi M., Tan C., Assadpour E., Jafar S. M. Oilseed meal proteins : From novel extraction methods to nanocarriers of bioactive compounds. *Food Chemistry*. 2024. № 438. URL: https://doi.org/10.1016/j.foodchem.2023.137971

8. Ivanova P., Chalova V., Koleva L., Pishtiyski I., Perifanova-Nemska M. Optimization of protein extraction from sunflower meal produced in Bulgaria. *Bulgarian Journal of Agricultural Science*. 2012. № 18 (2). Pp. 153–160. URL: https://www.agrojournal.org/18/02-02-12.pdf

9. Wang H., Johnson L. A., Wang T. Preparation of soy protein concentrate and isolate from extruded-expelled soybean meals. *Journal of the American Oil Chemists' Society*. 2004. № 81. Pp. 713–717. URL: https://doi.org/10.1007/s11746-004-966-8

10. Becze A. et al. Optimization of protein extraction from sunflower meal using Taguchi design and regression modeling for human nutrition applications. *Foods*. 2025. № 14 (14). URL: https://doi.org/10.3390/foods14142415

11. Kaur R., Ghoshal G. Sunflower protein isolates–composition, extraction and functional properties. *Advances in Colloid and Interface Science*. 2022. № 306. URL: https://doi.org/10.1016/j.cis.2022.102725

12. Codex Alimentarius Commission. *Standard for soy protein products (CXS 175-1989)*. 2022. URL: https://www.fao.org/fao-who-codexalimentarius/codex-texts/standards/en

13. van den Berg L. A., Mes J. J., Mensink M., Wanders A. J. Protein quality of soy and the effect of processing : A quantitative review. *Frontiers in Nutrition*. 2022. № 9. URL: https://doi.org/10.3389/fnut.2022.1004754

14. Rosentrater K. A., Zhang W. (2021). Techno-economic analysis of integrating soybean biorefinery products into corn-based ethanol fermentation operations. *Fermentation*. 2021. № 7 (2). URL: https://doi.org/10.3390/fermentation7020082

15. Sitnicki M., Kurinskyi D., Pimenowa O., Wasilewski M., Wasilewska N. Strategic formation of agricultural market clusters in Ukraine : Emerging as a global player. *Sustainability*. 2024. № 16 (21). URL: https://doi.org/10.3390/su16219430

16. Sitnicka K., Serhiienko R. Business Adaptation to Extreme Conditions : Analysis of Business Shocks in the Context of the War in Ukraine. *SocioEconomic Challenges*. 2025. № 9 (4). Pp. 216–255. URL: https://doi.org/10.61093/sec.9(4).216-255.2025

17. Ситницький М. В., Курінський, Д. О. Підписання тристоронньої зернової угоди як розв'язання організаційно-управлінських проблем агропідприємств України. Вісник *Київського національного університету імені Тараса Шевченка. Економіка*. 2022. № 4 (221) С. 58–63. URL: https://doi.org/10.17721/1728-2667.2022/221-4/8

18. Перегуда Ю. А. Цифровізація як драйвер впровадження циркулярних бізнес-моделей в агропромисловому комплексі. *Вісник Сумського національного аграрного університету. Серія «Економіка і менеджмент»*. 2026. № 2(106). С. 161–169. URL: https://doi.org/10.32782/bsnau.D2026.2.24

19. Pereguda Y., Biloshkurska N. Digital transformation as a strategic imperative for the development of innovative entrepreneurship in Ukraine in the context of international economic cooperation. *Соціальний розвиток : економіко-правові проблеми*. 2026. № 15. URL: https://doi.org/10.70651/3083-6018/2026.3.19

20. USDA Foreign Agricultural Service. *Oilseeds and products annual : Ukraine (Report UP2025-0008)*. 2025. URL: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds+and+Products+Annual_Kyiv_Ukraine_UP2025-0008

21. Кабінет Міністрів України. *Про схвалення Стратегії продовольчої безпеки України на період до 2027 року та затвердження операційного плану заходів з її реалізації*. Розпорядження № 684-р. 2026. URL: https://zakon.rada.gov.ua/go/684-2024-%D1%80

Kurinskyi, D. (2026). Circular redirection of protein flows in Ukraine's agri-food sector towards deeper-processed products. Management and Entrepreneurship: Trends of Development, 3(37), 12-28. https://doi.org/10.26661/2522-1566/2026-3/37-01

22. European Parliament and Council. Regulation (EU) 2015/2283 of 25 November 2015 on novel foods. *Official Journal of the European Union*. 2015. L 327. Pp. 1–22. URL: https://eur-lex.europa.eu/eli/reg/2015/2283/oj/eng

23. Кабінет Міністрів України. *Про затвердження Національного плану управління відходами до 2033 року та визнання такими, що втратили чинність, деяких актів*. Розпорядження № 1353-р. 2024. URL: https://zakon.rada.gov.ua/go/1353-2024-%D1%80

24. Ситницький М. В. Вплив інноваційного потенціалу на стратегічну гнучкість підприємства. *Статистика України*. 2007. № 1. С. 43-47.

25. Ситницький М. В., Курінський, Д. О. Управлінські перспективи розвитку вітчизняної аграрної галузі в умовах статусу України як кандидата у члени Європейського Союзу. *Ефективна економіка*. 2022. № 8. URL: https://doi.org/10.32702/2307-2105.2022.8.14

26. Sitnicki M., Balan V., Tymchenko I., Sviatnenko V., Sychova A. Measuring the commercial potential of new product ideas using fuzzy set theory. *Innovative Marketing*. 2021. № 17(2). Pp. 149–163. URL: https://doi.org/10.21511/im.17(2).2021.14

27. Sitnicki M.W., Wasilewska N., Balan V., Tymchenko I., Wasilewski M., Pimenowa O., Sitnicka S. Enhancing Strategic Flexibility for Sustainable Agro-Industrial Enterprises in Transition Economies : a Fuzzy Multicriteria Approach. *Technological and Economic Development of Economy*. 2026. № 32(3). Pp. 996–1023. URL: https://doi.org/10.3846/tede.2026.25543

ЦИРКУЛЯРНЕ ПЕРЕНАПРАВЛЕННЯ ПОТОКІВ БІЛКА В АГРОПРОДОВОЛЬЧОМУ СЕКТОРІ УКРАЇНИ НА ВИРОБНИЦТВО ПРОДУКЦІЇ З ВИЩИМ СТУПЕНЕМ ПЕРЕРОБКИ

Курінський Д. О.
Сумський національний аграрний університет
Суми, Україна
Selkat Holding
Сінгапур, Республіка Сінгапур

У дослідженні розглядається відсутність інструменту для порівняння економічного результату глибшої переробки соняшникового та соєвого шроту з альтернативними витратами, пов'язаними з використанням наявного експортного маршруту, а також із витратами на відбір придатної сировини. Запропоновано модель потоків матеріалів і білка, яка поєднує національну балансову тотожність, договірний і лабораторний контроль, обсяги виробництва продукції, масу білка та нормалізований чистий дохід за маршрутом. Результатом управлінського аналізу є визначення критеріїв попереднього відбору, порогових значень беззбитковості та запасів маржі для відхилення економічно вразливих маршрутів до проведення повної інвестиційної оцінки. Емпіричну базу становлять нові балансові оцінки FAS/Kyiv Post за 2024/25 маркетинговий рік (MY 2024/25), які розглядаються як цілісний інституційний масив даних, а не як офіційна статистика USDA. За базового охоплення 25% експорту обсяг придатної сировини становить 0,8988 млн. тонн, обсяг виробленої продукції - 0,4458 млн. тонн, а вміст білка в продукції - 0,2804 млн. тонн; сукупна додаткова маржа за двома напрямами становить 23,60 млн. дол. США. Беззбиткові нормалізовані чисті доходи від реалізації продукції становлять 1 031 дол. США за тонну для соняшникового маршруту та 959 дол. США за тонну для соєвого маршруту, що залишає запас міцності лише на рівні 6,3% та 4,1% відповідно. Для виробничої лінії потужністю 100 тис. тонн фактична переробка має охоплювати 7,4% експорту соняшникового шроту або 7,2% експорту соєвого шроту, тоді як контрактний та лабораторний скринінг має охоплювати 13,4% та 9,7% відповідних потоків. Незмінний зафіксований обсяг внутрішнього використання встановлюється як обмеження, пов'язане з кормовим використанням, тоді як циркулярність потребує окремої перевірки залишкових фракцій, води, енергії та стічних вод. Модель підтримує попередню оцінку перед

eISSN 2522-1566
ISSUE 3 (37), 2026

інвестуванням та вибір пілотного маршруту; вона не замінює техніко-економічного обґрунтування або інвестиційної оцінки на рівні конкретного проєкту.

Ключові слова: циркулярна економіка, потоки білка, соняшниковий шрот, соєвий шрот, білковий баланс, глибока переробка, експортний чистий прибуток, кормова безпека, продовольча безпека України, стратегічне управління.