Strategic Pathways for the Olive Oil Chain in Argentina: Profitability, Sustainability and Oleo tourism

Rutas estratégicas para la cadena de aceite de oliva en Argentina: rentabilidad, sostenibilidad y oleoturismo

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Abstract

The olive oil agri-food chain in Argentina is strategically relevant for rural development, employment, exports and tourism. Despite quality production and industrial capacity, the sector faces structural problems: high labour and energy costs, limited domestic consumption, and dependence on subsidized international competitors. This study analyses the chain using multicriteria programming across five dimensions: productive, economic-financial, commercial, environmental and tourism-territorial. The baseline was built from data collected between 2018 and 2024 (Agricultural Census 2018, official reports and international benchmarks), covering the country's most representative producing regions (Catamarca, La Rioja, San Juan and Mendoza), which together account for over 90% of national output. Results from scenario simulations reveal trade-offs: export-oriented strategies maximize profit but increase vulnerability to global prices; internal consumption growth strengthens resilience yet moderates revenues; environmental sustainability improves efficiency through lower water use; and balanced development with olive oil tourism achieves robust outcomes across all dimensions. A novel contribution is the quantitative inclusion of tourism, showing its potential to generate rural employment and enhance brand value. The findings support forward-looking strategies that combine technological reconversion, market diversification, efficient resource use and tourism integration, offering policy guidelines for sustainable territorial development.

Keywords
olive oil supply chain • costs • competitiveness • sustainability • bioeconomy • tourism • Argentina

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Resumen

La cadena agroalimentaria del aceite de oliva en Argentina es estratégica para el desarrollo rural, el empleo, las exportaciones y el turismo. A pesar de su calidad productiva y capacidad industrial, el sector enfrenta problemas estructurales: altos costos laborales y energéticos, bajo consumo interno y dependencia de competidores internacionales subsidiados. Este estudio analiza la cadena mediante programación multicriterio en cinco dimensiones: productiva, económico-financiera, comercial, ambiental y turística-territorial. El escenario base se construyó con datos relevados entre 2018 y 2024 (Censo Agropecuario 2018, informes oficiales y referencias internacionales), abarcando las provincias más representativas (Catamarca, La Rioja, San Juan y Mendoza), que concentran más del 90% de la producción nacional. Los resultados de las simulaciones por escenarios evidencian compensaciones: las estrategias orientadas a la exportación maximizan beneficios pero aumentan la vulnerabilidad a precios globales; el desarrollo del consumo interno fortalece la resiliencia aunque reduce ingresos; la sostenibilidad ambiental mejora la eficiencia al reducir uso de agua; y un desarrollo equilibrado con oleoturismo logra resultados robustos en todas las dimensiones. El aporte novedoso es la incorporación cuantitativa del turismo, que muestra su potencial para generar empleo rural y valor de marca. Los hallazgos sustentan estrategias prospectivas que combinan reconversión tecnológica, diversificación de mercados, uso eficiente de recursos e integración turística, ofreciendo lineamientos para políticas públicas y desarrollo sustentable.

Palabras clave

cadena de valor del aceite de oliva • costos • competitividad • sustentabilidad • bioeconomía • turismo • Argentina

Introduction

Argentina's olive oil sector holds strategic relevance not only for its product but also for its role in rural development, employment, and the diversification of semi-arid territories. Extra virgin olive oil (EVOO) from Argentina has achieved international recognition for quality (Benencia *et al.*, 2014), supported by industrial capacity and technological advancement. However, the sector faces persistent structural problems: high labour and energy costs compared to competitors (Ministerio de Economía, 2024), strong dependence on subsidized producers such as Spain and Italy, and limited domestic demand (CREA, 2021). These factors have hindered competitiveness and limited the capacity to capture value at national level. Argentina ranks 10th worldwide in olive oil production, with annual outputs fluctuating between 28,000 and 36,000 tons in peak years (IOC, n. d.; Ministerio de Economía, 2024). The sector employs around 30,000 temporary rural workers, equivalent to nearly three million daily wages per year (CREA, 2021), representing 8.1% of the national agricultural labour requirement. Despite this production capacity, domestic consumption remains extremely low (180-250 cc per capita annually), far below Mediterranean standards (Spain: ~15 litters per capita). This imbalance highlights a major challenge: while Argentina has structural potential, it captures limited value internally, depending heavily on exports and leaving domestic demand underdeveloped. These structural conditions justify the need for a comprehensive approach that analyses the chain not only in economic terms but also through its productive, commercial, environmental and territorial dimensions. Beyond its productive dimension, the olive oil chain must be understood as a networked agri-food system, where interdependencies extend to logistics, marketing, tourism and environmental management (García-Cascales *et al.*, 2021). This broader view enables policies to shift from a narrow "sectoral plan" to a flexible "roadmap" capable of adapting to disruptive changes in technology, trade and regulations (Romero, 1993). Moreover, the concept of bioeconomy reinforces this approach: olive cultivation generates biomass, by-products and ecosystem services whose valorisation expands the economic and territorial impacts (Stark *et al.*, 2021). The present study therefore adopts an integrated five-dimension perspective: (i) productive efficiency, (ii) economic-financial profitability, (iii) logistics and commercialization, (iv) environmental sustainability, and (v) tourism and territorial valorisation. This framework moves beyond isolated analysis of costs or yields, proposing instead a systemic evaluation of Argentina's olive oil chain as both a production network and a driver of local development. The research is guided by the following objectives:

(a) analyse the chain's structure and bottlenecks.
(b) simulate scenarios of value creation through multicriteria programming; and
(c) evaluate trade-offs between profitability, sustainability, domestic demand and oleo tourism.

The central hypothesis is that multicriteria programming can identify optimal strategic pathways for the olive oil chain in western Argentina, showing that a balanced approach integrating technological reconversion, sustainability and tourism improve resilience and competitiveness compared to purely export-oriented strategies. The analysis focuses on Argentina's main producing provinces (Catamarca, La Rioja, San Juan and Mendoza), which together account for over 90% of national olive oil output. While the baseline data correspond to 2018-2024, the scenarios are prospective, designed to explore strategic pathways for the future of the sector.

Materials and Methods

Methodological Approach: Multicriteria Linear Programming (MCP)

The methodological framework chosen was Multicriteria Linear Programming (MCP), as it enables the simultaneous evaluation of multiple, and often conflicting, objectives relevant to the olive oil value chain. This approach goes beyond single-objective optimization by capturing trade-offs between profitability, production, market allocation, environmental impacts and tourism valorisation. The focus of this study is not on statistical sampling, but on the integration of aggregated data from national censuses, official sectoral reports and international benchmarks. In this sense, concepts such as "sample" or "survey" are not applicable, since the analysis is systemic and chain oriented. The model is structured across five dimensions -productive, economic-financial, commercial, environmental, and tourism-territorial- which together reflect the sustainability and strategic development goals of the sector. Within this framework, MCP was applied to determine the optimal allocation of land, production, investments and market shares under real-world constraints. The method allows the generation of Pareto-efficient solutions, making visible the compromises between objectives and enabling the design of alternative strategic scenarios. This orientation provides a rigorous yet flexible analytical tool, adaptable not only to olive oil but also to other perennial crop systems embedded in similar ecological and territorial contexts (García-Cascales *et al,* 2021; Romero, 1993).

Justification of Multicriteria Programming (MCP *vs.* MCDM)

The choice of Multicriteria Linear Programming (MCP) is justified by the complexity of the olive oil value chain, where multiple and often conflicting objectives must be considered simultaneously. Traditional single-objective models fail to capture trade-offs between profitability, domestic consumption, exports, environmental impact and tourism valorisation. MCP provides a quantitative framework that integrates these dimensions and generates optimal solutions under real-world constraints. It is important to distinguish MCP from Multicriteria Decision Making (MCDM) approaches: while MCDM is designed to select among a finite set of alternatives (qualitative decision-making), MCP allows continuous optimization of resource allocation across multiple objectives. This distinction is relevant because the study does not evaluate pre-defined options but rather allocates hectares, production volumes and investments dynamically, reflecting real strategic planning needs.

The capacity of MCP to explore Pareto-efficient solutions and identify trade-offs among objectives strengthens its applicability to agri-food systems embedded in uncertain international markets and resource constraints (García-Cascales *et al,* 2021; Romero, 1993).

Data Collection and Update

Data consolidation was carried out by integrating official and sectoral sources rather than through statistical sampling. The structural base was provided by the 2018 National Agricultural Census (INDEC, 2019), complemented with annual sectoral reports from the Ministerio de Economía (2024), CREA (2021), and international benchmarks (IOC, 2015). Production volumes, costs and yields were compiled from these sources, covering the four main olive-producing provinces (Catamarca, La Rioja, San Juan, Mendoza). Given Argentina's inflationary context, all values were expressed in constant U.S. dollars, updated through official price indices. This procedure ensured comparability with international cost studies and positioned Argentina in a medium-to-high cost range relative to major competitors such as Spain and Portugal. As a result, the estimated average cost of a 500 ml bottle of olive oil was US$3.26, distributed as 50% primary production, 19% industrial processing and 31% packaging and fractionation. This calculation does not stem from a statistical survey but from sector-wide structural data, reflecting the systemic focus of chain analysis. Therefore, terms like "sample" or "survey" are not applicable: the analysis is based on censual and aggregated information integrated into the programming model income. From a bioeconomy perspective, olive cultivation also generates by-products such as pomace, pits, leaves, and pruning residues. These can be valorised through energy (biofuels, pellets), compost and soil amendments, animal feed, as well as tourism and ecosystem services. Although not explicitly included as decision variables in the model, these alternatives were acknowledged as part of the conceptual framework.

Continuous Decision Variables

The following decision variables capture the strategic choices available to the olive oil chain. They are associated mainly with the productive, commercial and tourism dimensions, representing cultivated hectares, production volumes, market allocation, and visitor flows. These variables are optimized by the model to explore alternative scenarios and resource allocation strategies.

- H_{trad}: Hectares in production of traditional olive groves (ha).
- H_{int}: Hectares in production of intensive olive groves (ha).
- Q_{trad}: Olive oil production obtained from traditional systems (ton).
- Q_{int}: Olive oil production obtained from intensive systems (ton).
- E: Volume of olive oil destined for export (ton).
- D: Volume of olive oil destined for the domestic market (ton).
- M: Investment in marketing and promotion for the domestic market (millions of USD).
- T_i: Number of tourists visiting province i (persons), quantifying olive oil tourism activity in each region.
- I_i: Investment in tourism infrastructure and promotion in province i (millions of USD), reflecting strategic capital allocation for tourism development.
- (H_{org}): Hectares under organic certification (optional, if a specific organic production objective is modelled).

Parameters (Fixed by Scenario or Context):

The parameters correspond to fixed or contextual values that condition the system. They include aspects of the productive dimension (yields, water and energy use), the economic-financial dimension (costs, prices, taxes), the environmental dimension (emission coefficients, water limits), and the tourism-territorial dimension (capacity, income per visitor). By defining these constants, the model ensures comparability across scenarios and consistency with official and international data sources.

r_{trad},r_{int}: Oil yield per hectare (ton/ha) for traditional and intensive systems, respectively (e.g., r_{trad}=0.5,r_{int}=1.5 ton/ha).

α_{trad},α_{int}: Water requirement per hectare (m^3/ha) for traditional and intensive systems (e.g., α_{trad}=3000, α_{int}=5000).

β_{trad},β_{int}: Energy consumption per hectare (kWh/ha) for traditional and intensive systems (e.g., β_{trad}=50,β_{int}=200).

P_{exp},P_{dom}: Price per ton of oil in the export and domestic market (e.g., P_{exp}=4000,P_{dom}=3500 USD/ton).

t_{exp}: E_{xport} tax rate (decimal, e.g., t_{exp}=0.05).

c_{trad},c_{int}: Total cost per ton of oil produced in each system (e.g., c_{trad}=3800,c_{int}=2300 USD/ton).

C_{mkt}: Marketing cost per ton for the domestic market (e.g., C_{mkt}=500 USD/ton).

W_{max}: Total water availability for irrigation (m^3) (e.g., W_{max}=300×106 m^3).

H_{max}: Maximum usable area for cultivation (ha) (e.g., H_{max}=90,000 ha).

p_i: Average income per tourist in province i (USD/tourist).

e_i^T: Associated jobs per tourist in province i (jobs/tourist).

e_i^A: Associated jobs per ton of oil produced in province i (jobs/ton).

c_i^T: CO_2 emission coefficient per tourist in province i (kg CO_2/tourist).

c_i^A: CO_2 emission coefficient per ton of oil in province i (kg CO_2/ton).

$capacitat_e$: Installed tourist capacity limit in province i (persons/day).

σ: Tourist seasonality coefficient (decimal).

C_{max}: Maximum allowed CO_2 emissions limit (kg CO_2).

personal disponible: Total available rural labour (jobs).

Objective Functions of the Integrated Model

The model incorporates multiple objective functions, each reflecting a strategic goal of the olive oil chain. Together, they cover the five sustainability dimensions:

• Economic-financial: profitability maximization.

• Productive: total oil production.

• Commercial: exports and domestic demand.

• Environmental: efficient use of resources and reduced footprint.

• Tourism-territorial: revenues, employment and territorial valorisation.

This configuration allows the model to simulate different policy or market priorities and to quantify their trade-offs.

Economic (Z_{econ}): Maximization of Net Profit

This function maximizes the net margin, considering sales revenues (export and domestic) and total costs (agricultural, industrial, commercial, taxes, marketing).

$$Z_{econ}=(1-t_{exp})P_{exp}E+P_{dom}D-c_{trad}Q_{trad}-c_{int}Q_{int}-C_{mkt}D$$

Technical (Z_{tec}): Maximization of Total Oil Production

This objective reflects the pursuit of productive efficiency and optimal input use, boosting agricultural and industrial yields.

$$Z_{tec}=Q_{trad}+Q_{int}$$

Commercial-External ($Z_{com\text{-}ext}$): Maximization of Exported Volume

This objective incentivizes allocating the largest possible production to external markets, capitalizing on the quality advantage of Argentine oil and consolidating international presence.

$$Z_{com-ext}=E$$

Commercial-Internal ($Z_{com\text{-}int}$)

Maximization of Volume Destined for the Domestic Market

This objective seeks to increase internal olive oil consumption in Argentina, contributing to food security and cultural product development.

$$Z_{com-int}=D$$

Environmental (Z_{amb})

Minimization of Environmental Impact (Water and Carbon Footprint)

This objective focuses on reducing the value chain's environmental impact, promoting long-term sustainability. It is formulated as the minimization of water and energy use, and total CO_2 emissions from both oil production and tourist activities.

$$Z_{amb}=-(\alpha_{trad}H_{trad}+\alpha_{int}H_{int})-\gamma(\beta_{trad}H_{trad}+\beta_{int}H_{int})-\sum i(c_{iT}Ti+c_{iA}A_i)$$

where

γ = a weighting factor for energy.

Productive (Z_{sup})

Maximization of Olive Grove Area in Production

This objective seeks to expand the olive agricultural frontier and rehabilitate underutilized plantations, increasing sectoral productive potential.

$$Z_{sup}=H_{trad}+H_{int}$$

Tourism-Revenue ($Z_{tur-ing}$)

Maximization of Olive Oil Tourism Revenue

This function maximizes income generated by visits to oil mills, tastings, tourist product sales, and accommodation services.

$$Z_{tur-ing}=\sum_i p_i T_i$$

Tourism-Employment ($Z_{tur\text{-}emp}$)
Maximization of Rural Employment Associated with Tourism

This objective focuses on maximizing job creation in rural areas, including guides, accommodation, and catering staff, contributing to curbing depopulation.

$$Z_{tur-emp}=\sum_i(e_{iT}T_i+e_{iA}A_i)$$

Tourism-Territorial Valorisation ($Z_{tur\text{-}val}$)
Maximization of Territorial Valorization

This objective, partly qualitative, seeks to intensify the social and economic recognition of the olive growing landscape as a heritage resource. It can be modelled as a tourist satisfaction index, a brand score, or a weighted sum of income per tourist and quality certifications (DOP/IG), reflecting public appreciation for authenticity, quality, and local culture.

Restrictions of the Integrated Model

The restrictions define the operational, resource and environmental boundaries within which the system must operate. They ensure feasibility of the solutions by linking production with demand, limiting land and water use, respecting labor and capacity constraints, and capping environmental impacts. In this way, restrictions reflect the real conditions faced by the olive oil chain and guarantee that the scenarios generated are both consistent and applicable:

Production-Market Balance

All oil production must be assigned to a market (internal or external), assuming no significant stock variations.

$$Q_{trad}+Q_{int}=D+E$$

Production Limits per System

The oil production of each system cannot exceed its potential yield per hectare.

$Q_{trad} \le r_{tradHtrad}$

$Q_{int} \le r_{int}H_{int}$

Water Availability

Total water consumption for irrigation cannot exceed the maximum available annual allocation.

$$\alpha_{trad}H_{trad}+\alpha_{int}H_{int} \le W_{max}$$

Land Availability

The total cultivated area cannot exceed the maximum usable area.

$$H_{trad}+H_{int} \le H_{max}$$

Maximum Internal Demand

The demand of the internal market can be limited by its maximum consumption potential.

$$D \le D_{max}$$

Installed Tourist Capacity

The number of tourists in each province cannot exceed the physical capacity of local tourist infrastructures.

$T_i \le Capacity$ (*e.g.*, Mendoza's olive oil tourism providers can serve about 2,533 people per day).

Tourist Seasonality

The annual tourist offer may be limited by seasonal factors, reflected by a coefficient.

$$T_i \le Capacity \times Operative\ days$$

CO_2 Emissions Limit

Total emissions generated by production and tourism must not exceed a maximum threshold, reflecting a commitment to environmental sustainability.

$$\sum_i (c_{iT} T_i + c_{iA} A_i) \leq C_{max}$$

Labour Balance

The total rural labour required for agricultural and tourist activities cannot exceed the availability of personnel.

$\sum_i (w_{iT} T_i + w_{iA} A_i) \leq$ *personal disponible* (where w_{iT} and w_{iA} are labour coefficients per tourist and per ton of oil, respectively).

Budgetary Restrictions for Tourist Investment

Investment in tourism in each province may be limited by available financing.

$$I_i \leq \text{Tourism Investment Budget}$$

Non-Negativity

All decision variables must be greater than or equal to zero.

$$H_{trad}, H_{int}, Q_{trad}, Q_{int}, D, E, M, T_i, I_i \geq 0$$

Transformation to Goal or Weighted Model

To solve this multi-objective programming problem, the approach of weighted goal programming or the weighted sum of objective functions can be adopted. Goal programming allows for the establishment of a desired level for each objective, subsequently minimizing deviations from these targets using deviation variables (d_i-,d_i+) to represent non-compliance or excess.

Alternatively, and often more intuitively for scenario exploration, a single scalar function can be defined as the weighted sum of all individual objective functions:

$$\max Z_{total} = \omega econ Z_{econ} + \omega tec Z_{tec} + \omega_{com}\text{-}extE + \omega com\text{-}intD + \omega amb Zamb + \omega sup H + \omega_{tur}\text{-}ing Z_{tur}\text{-}ing + \omega_{tur}\text{-}e_{mp} Z_{tur}\text{-}e_{mp} + \omega tur\text{-}val Ztur\text{-}val$$

Here, ωk represents the weights assigned to each objective, reflecting its strategic priority in a given scenario. It is crucial to normalize or scale the objective functions prior to assigning weights, as their units and magnitudes vary significantly (e.g., Z_{econ} in millions of USD, Z_{tec} in thousands of tons, Z_{amb} in millions of m^3 or kg CO_2). This normalization ensures that the weights accurately reflect the relative importance of each objective. By adjusting these weights, this method enables the emulation of various strategic scenarios and the identification of efficient Pareto solutions, which represent the best possible compromises among conflicting objectives.

Results

Descriptive Overview of the Argentine Olive Oil Sector

As described in the Introduction, Argentina is a mid-scale producer with low domestic consumption. Building on this context, the following overview summarizes sectoral features relevant for scenario modelling. The low domestic consumption, despite Argentina being a producing nation, suggests either a market failure or a lack of strategic focus on developing internal demand. This presents one of the most significant opportunities for the Argentine olive oil business strategy: internal consumption could potentially increase by 500% to reach one litter per capita per year, though even this would remain minimal compared to European averages. Globally, olive oil consumption has seen an average annual growth of approximately 3.5% over the last five years, indicating a favourable international trend.

In 2021, the sector's total turnover, encompassing both internal consumption and exports, reached US$223 million, with olive oil accounting for 57% and table olives for 43%. The predominant primary production system in Argentina is traditional, although newer plantations have adopted more efficient crown systems (MAGyP, 2023). The country boasts excellent olive varieties and the potential for qualifying specific geographical indications. The industrial oil sector comprises approximately 120 processing establishments, which vary in size, personnel, and performance.

For the domestic market, which accounts for about 20% of total production, sales volume is distributed across major regions: AMBA (Área Metropolitana de Buenos Aires) (CABA Ciudad Autónoma de Buenos Aires and 40 municipalities of Provincia de Buenos Aires) (50-58%), Interior de Buenos Aires) (15%), Litoral and NEA (NEA: Northeast Area) (10-11%), Cuyo and NOA (Nordeste Argentino) (9-10%), Córdoba (6-7%), and the Patagonia (Patagonia: South Area) Area (3-4%). The 500cc container is the best-selling format, comprising 89% of the market, significantly outpacing the 1-liter container (7.4%). PET containers are the most widely used (35-45%), followed by cans (30-35%), while glass accounts for 12-17% of sales. Approximately four brands (SolFrut/Oliovita, Nucete, AGD/Zuelo, Laur/Fam. Millán) dominate the market as the dominant finge and the rest integrate the competitive fringe in the mixed oligopoly structure.

Quantitative Performance by Scenario

The multicriteria model quantifies the Argentine olive oil value chain's performance under various strategic priorities. Table 1 summarizes key outcomes: estimated annual net profit, total olive oil production, exports, internal consumption, annual irrigation water usage, and total cultivated area. For the balanced development and value added with olive oil tourism scenario, values are hypothetical, showing the potential of this integrated approach.

Table 1. Quantitative performance by scenario.

Tabla 1. Rendimiento cuantitativo por escenario.

Scenario	Net Profit (USD million/year)	EVOO Production (ton/year)	Exports (ton/year)
Base (Conservative)	~10 (low)	~35,000	24
Export-Oriented	140 (very high)	95	85
Internal Consumption	~50 (moderate)	~50,000	~35,000
Environmental Sustainability	~100 (high)	~80,000	~70,000
Balanced Development and Value Added with Olive Oil Tourism	~110 (high)	~70,000	~50,000
Scenario	**Internal Consumption (ton/year)**	**Water Used (Mm^3/year)**	**Area in Production (ha)**
Base (Conservative)	~8,000	210	~70,000
Export-Oriented	~10,000	300 (100% avail.)	~90.000
Internal Consumption	15	~250	~80,000
Environmental Sustainability	~10,000	250 (83% avail.)	~75,000
Balanced Development and Value Added with Olive Oil Tourism	~12,000	~270	~85,000

A novel contribution of this study is the quantitative inclusion of olive oil tourism as a modelled variable. This expands traditional economic-environmental analyses by incorporating territorial valorisation and rural employment, aspects rarely integrated in optimization models of agri-food chains. The Base (Conservative) scenario shows low profit (~US$10 million) from narrow margins and low production (~35,000 tons). Most production (24,000 tons) is exported, with minimal domestic consumption (8,000 tons). Despite not maxing out water use, it's inefficient, with high water consumption per ton and underutilized capacity.

The Export-Oriented scenario achieves the highest profit (US$140 million) by nearly tripling production (95,000 tons) and massively increasing exports (85,000 tons). This model uses maximum land (90,000 ha) and all available water (300 Mm^3). While water efficiency improves, domestic consumption barely rises, showing a strong external market focus.

The Internal Consumption scenario significantly boosts domestic availability, with 15,000 tons for local use, nearly doubling current levels. Total production rises to 50,000 tons, reducing exports to 35,000 tons. Net profit is US$50 million, lower than the export scenario but much higher than the base. Water use (250 Mm^3) is below maximum, and cultivated area reaches 80,000 ha. This approach prioritizes the domestic market, accepting some trade-off in export revenue.

The Environmental Sustainability scenario balances high production (80,000 tons) and exports (70,000 tons) with substantial profit (US$100 million). Notably, it achieves this while using 50 Mm^3 less water than the export scenario, highlighting water-saving technologies. Its water efficiency is highest, and it uses less land (75,000 ha) for significant volume. Domestic consumption remains low. This shows that high volumes are possible with reduced water impact, even if profit is slightly lower due to initial costs or less aggressive resource use. It demonstrates that a balanced approach yields broader benefits than maximizing a single objective.

Finally, the Balanced Development and Value Added with Olive Oil Tourism scenario offers a well-rounded profile. With US$110 million profit, it produces 70,000 tons, exporting 50,000 and allocating 12,000 to domestic consumption. Water use (270 Mm^3) is efficient, and it uses 85,000 ha. While not maximizing any single objective, it shows the chain's ability to generate significant income and rural employment through tourism, while performing strongly across production, commerce, and environment (Guida-Johnson *et al.*, 2024) . The comparative visualizations reinforce the multidimensional nature of trade-offs, directly linking results to the five sustainability dimensions outlined in the Introduction

Figure 1 (page 97), visually compares these scenarios using a radar chart, showing their relative performance across five key areas: Economic Benefit, Total Production, Internal Consumption, Water Efficiency, and Area Used. Each axis is normalized from 0 (worst) to 100 (best).

(Elaboration based on the conceptual radar chart described in the source document)

The export-oriented scenario (orange line) excels in Economic Benefit, Total Production, Area Used, and Water Efficiency, but lags in Internal Consumption. The internal consumption scenario (red line) leads in Internal Consumption, but scores lower in Economic Benefit and Water Efficiency. The environmental sustainability scenario (magenta line) is balanced, with high Water Efficiency and strong performance in Production, Area Used, Economic Benefit, and Internal Consumption. The base scenario (yellow line) consistently underperforms. The Balanced Development and Value Added with Olive Oil Tourism scenario (blue line, hypothetical) shows solid, consistent performance across all dimensions, including additional benefits from tourism not directly shown here, like tourism revenues and rural employment. Figure 2 (page 97), presents radar charts comparing the performance of Argentina's four main olive-producing provinces (Catamarca, La Rioja, Mendoza, and San Juan) under different strategic scenarios. This visual analysis confirms that no single strategy is universally best; the optimal choice depends on specific priorities. The results also identify leverage points for improvement, particularly technological reconversion in primary production to reduce unit costs, diversification of products and markets to stabilize demand, and investment in tourism infrastructure to enhance value creation. These elements extend beyond descriptive analysis, offering actionable strategies for sectoral competitiveness.

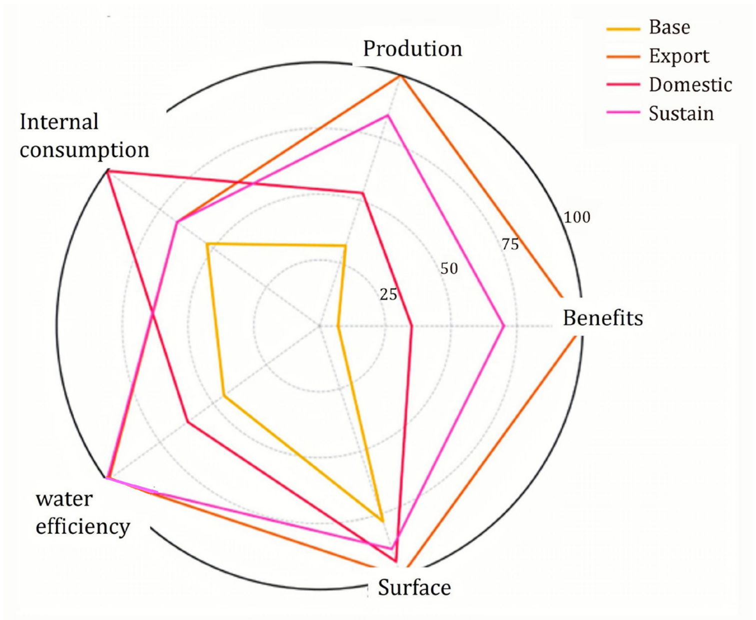

Figure 1. Comparison of relative performance of strategic scenarios on key criteria.

Figura 1. Comparación de desempeño relativo de los escenarios estratégicos en criterios clave en las principales provincias productoras.

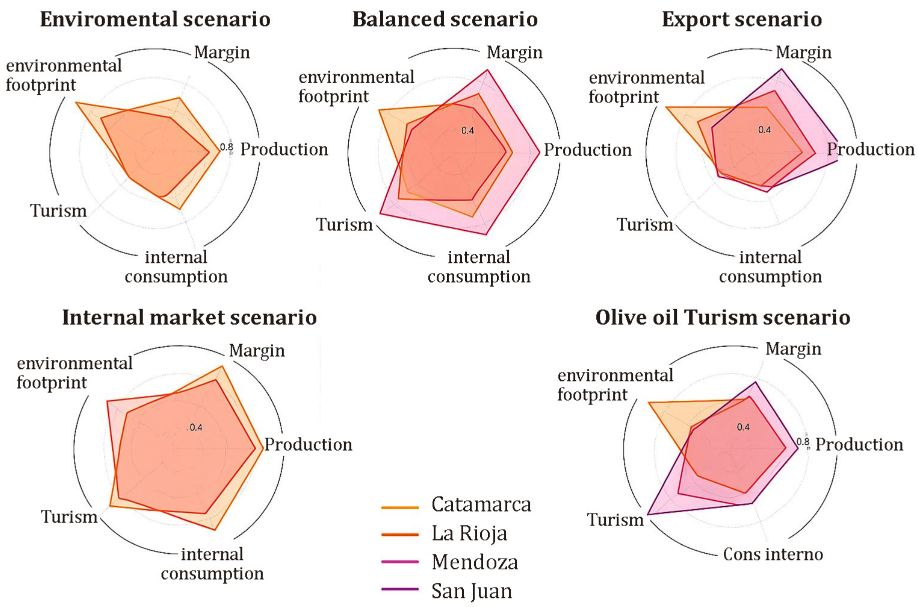

Figure 2. Impacts of each scenario in the main producing provinces.

Figura 2. Impactos de cada escenario en las principales provincias productoras.

Iterations and Sensitivity Analysis

While scenarios provide specific performance points, sensitivity analysis and gradual iterations are crucial to understand how optimal solutions shift with changing priorities or parameters, defining the Pareto frontier. This helps answer questions about trade-offs, such as how much economic gain must be sacrificed for water savings or increased domestic consumption.

Sensitivity to Domestic Objective Weight (ωD)

Increasing the importance of domestic consumption (ωD) in an export-focused model shows how production shifts from external to local markets. Initially, small increases in domestic consumption have minor profit impacts. However, pushing domestic consumption beyond 12,000-15,000 tons leads to significant economic losses, as the model must sacrifice profitable exports or expand production less efficiently. This indicates diminishing returns for boosting internal consumption; a compromise point around 12,000 tons allows maintaining about 75% of original exports. Beyond this, each extra domestic ton roughly replaces an export ton, further reducing profit. This analysis is vital for setting realistic domestic consumption targets.

Sensitivity to Water Limit (W_{max})

Reducing water availability in the export-oriented model by 10% (from 300 Mm^3 to 270 Mm^3) cut optimal production by about 15% and exports by 18%. This means a small water reduction leads to a proportionally larger drop in exportable output, as the model replaces water-intensive intensive hectares with less productive traditional ones or leaves land uncultivated. In contrast, the environmental sustainability scenario saw less than a 10% production drop with the same water restriction, as it already operates efficiently. This suggests that environmentally optimized olive growing is more resilient to water scarcity, highlighting sustainability practices as enhancing operational resilience.

Impact of International Price

A significant drop in international olive oil prices (*e.g.*, from US4,000 to US3,000 per ton) would drastically reduce the export-oriented model's profitability, potentially halving sectoral benefit. In such a case, the optimal strategy would shift towards the domestic market, as the price difference narrows. This suggests that promoting internal consumption can act as a counter-cyclical policy, providing a stable domestic market buffer against global price volatility (Pérez-Aleman, 2012).

Pareto Analysis (Benefit vs. Water Footprint)

A Pareto analysis showed that the first 50 Mm^3 of additional water (from 200 to 250 Mm^3) significantly boost production and profit. However, beyond 250-260 Mm^3, the marginal profit from additional water diminishes, following the law of diminishing returns. This indicates an optimal point where further water use yields minimal economic gain, making water conservation highly justifiable. Around 250-260 Mm^3, conserving 40-50 Mm^3 (about 15%) barely reduces maximum profit by 5-10%. This provides a quantitative basis for sustainable water management.

Land vs. Technology (Intensive vs. Traditional Hectares)

Optimized model runs consistently showed that intensive hectares (H_{int}) are maximized before expanding traditional ones (H_{trad}), as intensive systems are more resource efficient. Only when H_{int} was artificially limited did the model expand H_{trad} significantly, but this led to lower overall production and no notable water savings. This confirms the importance of technological reconversion: prioritizing modern, productive systems is more advantageous for maximizing yield and efficiency than simply increasing cultivated land.

Sensitivity to Olive Oil Tourism Integration

Integrating olive oil tourism allows evaluating how increased tourism investment (Ii) impacts visitors (Ti), tourism revenues, rural employment, and overall economic benefit. For example, analysing Mendoza's tourist capacity (approx. 2,500 people/day) reveals tourism growth potential with infrastructure expansion or diversified offerings to reduce seasonality. A Pareto analysis between tourism revenues and carbon footprint (including transport emissions) would show trade-offs between tourism growth and environmental goals. If olive oil tourism enhances brand image and quality perception (*e.g.*, through certifications), it could increase export prices (P_{exp}) for premium products, mitigating economic trade-offs and generating quantifiable intangible benefits. Beyond direct revenue, tourism acts as a marketing multiplier, boosting brand value and potentially increasing premium product export prices, creating a virtuous cycle between tourism and product sales.

Overall, these iterations demonstrate the multicriteria model's sensitivity to varying preferences and parameters, allowing a comprehensive exploration of how optimal solutions shift with altered assumptions or strategic emphases, providing valuable planning information. This sensitivity analysis not only validates the robustness of the model but also supports the central hypothesis: balanced strategies integrating economic, environmental and tourism variables yield more resilient outcomes than single-objective approaches.

Discussion

The multicriteria optimization results confirm the initial hypothesis: no single-objective strategy is sufficient to ensure competitiveness and sustainability in Argentina's olive oil chain. Balanced approaches that integrate economic, environmental and territorial objectives provide more resilient outcomes, particularly under resource and price volatility. The Export-Oriented scenario demonstrates the sector's potential to generate high revenues yet reinforces dependence on international markets and exposes vulnerability to price fluctuations. Similar dynamics have been observed in Spain, where strong export orientation has increased exposure to EU policy shifts and global price cycles (IOC, 2015). By contrast, the Internal Consumption scenario highlights opportunities for domestic market development. Previous studies confirm that per capita consumption below 0.3 litters is anomalously low for a producing country (Benencia *et al.*, 2014), suggesting that targeted campaigns and tax incentives could unlock latent demand. The Environmental Sustainability scenario reveals that water and energy-efficient technologies allow significant production while reducing resource pressure. Comparable findings have been reported in Portugal, where reconversion to super-intensive systems doubled yields while reducing unit costs (Branquinho *et al.*, 2021). The novelty of this study lies in the Balanced Development with Olive Oil Tourism scenario, which integrates agricultural and service-based activities. Olive oil tourism has been qualitatively addressed in prior works (Enolife, 2025), but this model quantitatively demonstrates its capacity to generate revenues, rural employment and territorial branding. From a broader perspective, the olive oil chain should be understood as an agri-food network or "entramado", not just a linear chain (Díaz-Chao *et al*., 2016). This resonates with bioeconomy approaches that emphasize valorisation of biomass and by-products, ranging from pomace energy use to ecosystem services. Incorporating this perspective enriches the interpretation of results: scenarios that prioritize diversification, circular use of resources and tourism services achieve more robust territorial impacts. Overall, the findings demonstrate that policy strategies for the olive oil sector must balance profitability, sustainability and territorial development. These results contribute to the literature on multicriteria programming applied to agri-food systems by explicitly incorporating tourism and territorial valorisation (Millán-Vázquez de la Torre *et al.*, 2017). They also provide actionable insights for public policy, suggesting that integrated sectoral planning should foster innovation, sustainability and experiential marketing as complementary drivers of competitiveness. The acknowledgment of these biomass valorisation pathways reinforces the interpretation of the olive oil chain as a bioeconomic network, extending its impact beyond oil production toward energy, environmental services, and territorial development.

Recommendations

Strengthen The Domestic Market

- Increase per capita consumption (≈0.3-0.5 kg) through fiscal incentives, educational campaigns and promotional programs.

- This provides a buffer against international price volatility.

Promote Technological Reconversion

• Modernize groves (super-intensive systems, mechanization, replanting).

• Reduces unit costs and improves competitiveness, following experiences in Chile and Portugal (Vargas & Garrido, 2019).

Diversify Products And Markets

• Expand exports beyond Brazil/USA toward emerging markets (China, India) and regional partners (Mexico, Colombia).

• Prioritize bottled EVOO under Argentine brands to capture more value.

Leverage Sustainability As Opportunity

• Implement certifications (organic, carbon-neutral, GAP).

• Access premium markets and align with global consumer trends.

Ensure Efficient Water Use

• Generalize technified irrigation, promote wastewater reuse and solar-powered pumping.

• Avoid exceeding thresholds where marginal returns diminish.

Integrate Olive Oil Tourism Strategically

• Develop routes, infrastructure and certified experiences.

• Generates rural employment, strengthens territorial identity and enhances brand value.

• Promote sustainable practices to minimize environmental trade-offs.

Conclusions

The results of the multicriteria programming model confirm that no single-objective strategy is sufficient to ensure competitiveness and sustainability in Argentina's olive oil chain. Instead, a balanced approach -integrating economic profitability, technological reconversion, environmental sustainability and tourism- yields the most resilient outcomes under volatile market and resource conditions. The analysis highlights three key findings: Technological reconversion in primary production is the most effective lever for reducing costs and improving international competitiveness. Domestic market development is feasible up to moderate levels, strengthening resilience without severely compromising export revenues. Olive oil tourism, when modelled quantitatively, emerges as a central driver of value creation, rural employment and territorial branding. These findings validate the initial hypothesis: balanced strategies outperform purely export-oriented or consumption-focused approaches. They also expand the literature by incorporating tourism and territorial valorisation into an optimization framework, offering a broader bioeconomic interpretation of value chains. Finally, the study provides actionable insights for public policy and sectoral planning: fostering innovation, sustainability and experiential marketing can consolidate Argentina's olive oil sector as a competitive and resilient player in global markets.

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