From used cooking oils to P3HB biopolymers, a techno-economic feasibility study for production plants in Italy to foster the creation of a new value chain

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This study conducted a comprehensive economic feasibility analysis of a biotechnological plant that converts used cooking oils into the poly-3-hydroxybutyrate (P3HB) polymer used as an ingredient by the cosmetics industry, especially as a UV filter. Its findings offer critical insights for stakeholders, investors, and industry practitioners regarding the economic viability and financial sustainability of the project. The study opens with an assessment of the compatibility of used cooking oils (UCOs) collected in the Lazio Region (Italy) with the biotechnological process, though chemical-physical analyses that were conducted on crude UCOs and treated UCOs. Technological feasibility and the estimated process yield were confirmed, followed by a simulation of Operational Expenditures (OPEX) to evaluate how profitability varies with production capacity. The smallest profitable production capacity was identified, and the corresponding plant was modelled for the economic feasibility analysis. The study concludes that UCOs from Lazio households are suitable feedstock for the Hydal® biotechnology producing P3HB for cosmetic applications, with a B2B market value of around 50 €/kg for the lowest product grades. Treated UCOs are preferred over crude UCOs due to their superior performance in fermentation and smoother environmental licensing processes. Financial indicators, including OPEX, ROI, and payback period, indicate that a 350 t/y capacity plant, starting with a two-year phase of 175 t/y, offers a promising business opportunity, with an average yearly ROI of 14.5% and a payback period of 4.1 years. Market fluctuations in demand and supply were analysed for robustness. While the costs of treated UCOs, electricity, and natural gas do not significantly impact OPEX and other financial indicators, another two cost items do so to a critical degree: labour costs and interest rates. Consequently, they must be thoroughly monitored to avoid falls in profitability, if P3HB selling prices remain unchanged. Nevertheless, the positive market outlook for P3HB in cosmetics, supported by EU legislation and the forecast growth in the relevant segments, underscores the project's potential. The market for P3HB-based cosmetic products, with segments such as upcycled ingredients, waterless cosmetics, UV protection, and natural and organic cosmetics, is forecast to grow significantly, reaching over 60 billion euros by 2024.

1. INTRODUCTION

In Italy, approximately 90-95,000 tons of used cooking oils (UCOs) are collected and exploited, making up one third of the total UCOs generated. [1] Used cooking oils, when properly collected, are one of the most widely recycled biowaste streams, mainly through the production of biodiesel. However biodiesel production from UCOs will face regulatory challenges in the near future [2] and new value chains are expected to devise and launch new UCO-derived products on the market. This is the case with the biodegradable and biocompatible biopolymer poly-3-hydroxybutyrate (P3HB) for cosmetics applications, of which the patented [3] and scalable production process from UCOs delivers a

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high-added value product, with remarkable economic revenues (B2B market price: 50,000-100,000 € / ton) and market reach. The production process starts with untreated UCOs and is free of toxins and GMOs. The biopolymer particles obtained display many remarkable properties: high UV absorption rates, non-toxicity, high biodegradability rates [4]–[6]. This technology is completely in accordance with sustainability goals and regulations, both current and predicted. [7]–[10]

The yield of the production process is around 52% and can be up to 70%, meaning the P3HB Italian market demand for cosmetics applications would require a small percentage of currently collected UCOs in Italy. This opens up the possibility of creating and expanding the value chain gradually without disrupting the currently established chains, even considering the growing market demand for natural and waterless cosmetics.

Within the framework of a project development assistance initiative for the Lazio Region (Italy), we performed a techno-economic feasibility study into the establishment of a full-scale industrial production plant in Lazio, building on the process and market parameters available from the demonstration plant currently operating in Prague in the Czech Republic. The demonstration plant's production capacity is insufficient to meet current market demand and the expansion of operations in Italy is being explored.

This expansion would involve the construction of a production plant able to convert more than 660 tonnes per year (t/y) of UCOs into 350 t of P3HB, preceded by a preliminary phase with a production capacity of 175 t/y (from 330 of t/y UCOs). There are several reasons for the implementation of a preliminary 175 t/y production phase in Italy. Firstly, the demand of the Italian market for specific P3HB particles must be tested and consolidated. Based on that, the production process parameters, operational intricacies and logistics considerations will be fine-tuned.

The purpose of this work is to conduct a comprehensive economic feasibility analysis encompassing both the initial 175-t/y phase and the subsequent proposed expansion to double production capacity. The findings of this research are expected to provide stakeholders, investors, and industry practitioners with crucial insights, facilitating informed decisions concerning the economic viability, financial outlook and sustainability of the proposed steps in plant construction.

2. METHODOLOGY

The authors first evaluated the compatibility of used cooking oils collected in Lazio with the biotechnological process required to convert them into P3HB. This was achieved through the chemical-physical analysis of two samples, one of crude UCOs and another of UCOs treated according to the Italian framework for the conversion of collected UCOs into secondary raw material for recycling processes. Details can be found in paragraph 2.1.

Once the technological feasibility and the estimated process yield were ensured, the authors followed the methodology laid out in paragraph 2.2 to simulate OPerational Expenditures (OPEX) and to understand how profitability varies with production capacity. Subsequently, the smallest profitable production capacity was identified and the corresponding plant was modelled and submitted to an economic feasibility analysis (details in paragraph 2.3).

2.1. CHEMICAL-PHYSICAL ANALYSIS

Two 1-kg samples of UCOs, one crude and one treated, were submitted to the following characterisation: acid value, saponification value, iodine value, peroxide values, solids content, aqueous phase content. Two replicates were conducted for each analysis. These values were monitored on fermentation entry as they have a profound impact on the fermentation yield and duration.

- Acid value: a precisely measured amount of 2 g of oil sample was dissolved in 10 ml of diethyl ether. Phenolphthalein was added and the sample solution was titrated with standardised 0.01M KOH solution in MeOH.
- Saponification value: a precisely measured amount of 0.3 g of oil sample was weighted in a closed cap tube, 5 mL of approx. 1M KOH in MeOH was added. The closed tube was placed for 1 hour in a water bath at 65°C and periodically shaken. On cooling down, the content was quantitatively transferred to an Erlenmeyer flask for titration, while 2x10 mL of EtOH was used for flushing the residues from the tube. The sample solution was then titrated using approx. 0.5M H_2SO_4, a solution preferred over the 0.5M HCl laid down by the standard methods ISO 3657:2020 and ASTM D5558 because, in our experience, it was more stable. Phenolphthalein was used as an indicator. Blank titration values were subtracted from the titration measurements of the samples.
- Iodine Value was determined according to the Wijs method in accordance with ISO 3961:2018.
- Peroxide value was determined in accordance with "Peroxide value of oils and fats 965.33.12. Official methods of analysis of AOAC international".

2.2. OPEX CALCULATION

OPEX was calculated on the simulations of three P3HB production capacities: 35 t/y, 175 t/y and 350 t/y. OPEX was obtained by updating existing economic studies performed with the Peters *et al.* model [11], which is described in detail in the next section, for the capacities considered and using late-2021 and early 2022 Czech market values. The following assumptions were made:

- the industrial site is rented (for all three plant capacities considered)
- the microbiological unit of the quality control laboratory and seed training lab and its personnel are always included
- some workers operate in shifts
- the process waste flow, a solution containing the residues of bacterial cells and cultivation broth, including residual UCOs, is treated off-site in an anaerobic digestion plant.

2.3. COST AND FINANCIAL EVALUATION OF A PRODUCTION PLANT

Once the production capacity was established on the basis of the OPEX analysis, a plant was simulated by Nafigate on the basis of their knowledge of the process and the facilities, acquired from the operation and the design optimization of the demonstration plant currently running in Prague (CZ) and the small-scale capacity (35t/y) plant under construction in Ostrava (CZ). The production plant for the selected capacity was submitted to economic and financial assessment in accordance with the model proposed by Peters *et al.* in “Plant Design and Economics for Chemical Engineers, 5th edition” [11]. This particular model’s strongpoint is its conciseness, encapsulating all the necessary factors to build and run a chemical plant in its four input sheets (“Capital Investment”, “Material and Labour”, “Annual Total Product Cost” and “Utilities”). The output sheets deliver an “annual total product cost at 100% capacity”, “economic evaluation” with Return on Investment (ROI), payback period, net return, discounted cash flow rate. The additional sheet “Year-0 $” is similar to the Evaluation sheet but delivers a more accurate view of the time value of money and its influence on project profitability and financial gains.

As well as the proper balance between data quantity and accuracy, the model offers a time resolution of 1 year, making it particularly suitable for the simulation of the economic and financial aspects of the initial stages of a production plant, be it a demo or a full-scale plant.

The model for chemical plants developed by Peters *et al*. [11] was considered the most appropriate of those for which suitability has been explored in the past, despite three main drawbacks: i) the conversion of UCOs into P3HB is a biotechnological process, not a chemical one, ii) the model does not accommodate highly specialized scenarios and iii) the model is dated and uses 2002 parameters. The authors addressed the first drawback by modifying weighing factors of cost items on the “Capital investment” sheet and including inputs for the biotechnology process among the rest of the input sheets. The second drawback was not detrimental since consideration was only given to the scenario of solely manufacturing of P3HB as material for use by others without the complication of a more complex business case, while the third was addressed by using economic data from projects conducted in the last couple of years and 2023 market values, updating financial parameters like loan interest and inflation rates. A list of all the modifications to Peters *et al*.’s model [11] is given in Table I.

In the initial phase, the model was filled with inputs from the Czech case, in CZK currency converted to EUR in accordance with the conversion rate in November 2023 (1 CZK = 0.0408 EUR). Later, to adapt the data to the specifics of the Italian case, a recalibration was undertaken by applying factors to entries like labour costs or energy cost, while other entries were left unchanged if they referred to the international market (i.e.: prices are consistent across Europe). This was the case with the equipment and machinery, raw material and inputs sold on the EU chemical commodity market, such as $MgSO_4 \cdot 7H_2O$, mineral nutrient solution, NH_3 24%, H_2SO_4 96%, NaOH 50%, KOH 45%, H_3PO_4 85%, HCl 35% and the bacterial seed.

The recalibration process ensures that the economic model and cost estimates reflect the unique conditions and considerations associated with the Italian context. All modifications required for the Italian case are also reported in Table I.

2.4. FINANCIAL MODELLING BASED ON CONSTRUCTED TECHNO-ECONOMICAL MODEL

In addition to the direct outputs of economical feasibility, taken directly from the constructed model in accordance with the inputs gathered, alternative scenarios were explored and tested in which the input costs might be different. For this assessment, the cost categories with the greatest operational impact were first selected based on the simple comparison of their percentage contribution to Annual Total Production Costs (TPC). The impact of these categories was further explored by varying the values used to assess the extent of each category’s impact. To facilitate the comparison of the effect of each cost category under consideration, the initial values were assigned as 100% and then the same percentage changes were made to each category during impact modelling. The values of only one category were changed at a time, so the other values remained constant when generating the modelling outputs. The average annual Return On Investment (ROI) was used as a simplified output to cover all the relevant financial issues. The results are presented in section 3.3.

Table I - Model inputs specific for a P3HB production plant. (n.a. = not applicable)

Data type	Specificities for P3HB production plant against a chemical plant (Czech case)		Conversions for the Italian case (Dec 2023)	
	location in the calculation sheet	**Rationale for the specificity**	**Conversion factor or direct cost**	**Rationale behind the change**
Purchased equipment	Capital investment	Based on data acquired from an inquiry procedure conducted across Europe in the middle of 2023	n.a.	n.a.
Purchased equipment installation	Capital investment	Expenditures computed based on data acquired from an inquiry procedure conducted in the CZ in 2021 and updated by inflation	1.79	Ratio between labour costs in Italy and CZ. [12]
Instrumentation & Controls(installed), Piping (installed), Electrical systems (installed)	Capital investment	Expenditures computed based on data acquired from an inquiry procedure conducted in the CZ in 2021 and updated by inflation	n.a.	n.a.
Buildings (including services),	Capital investment	The coefficients relevant for CZ are drawn from Roušar's manual on Czech Project management of technological buildings [13]	1.25	Ratio between building costs/m^2 in IT vs CZ (on residential buildings). No data available for industrial buildings. [14], [15]
Yard improvements	Capital investment	The coefficients relevant for CZ are drawn from Roušar's manual on Czech Project management of technological buildings [13]	1.25	Ratio between building costs/m^2 in IT vs CZ (on residential buildings). No data available for industrial buildings. [14], [15]
Service facilities (installed)	Capital investment	Expenditures computed based on data acquired from an inquiry procedure conducted in the CZ in 2021	n.a.	n.a.
Engineering and Supervision	Capital investment	Expenditures computed based on data acquired from an inquiry procedure conducted in the CZ in 2021 and updated by inflation	1.30	Ratio between labour costs for engineers in IT and CZ. [16]–[18]
Construction Expenses	Capital investment	The coefficients relevant for CZ are drawn from Roušar [13]	1.25	Ration between building costs/m^2 in IT and CZ (on residential buildings) No data available for industrial buildings. [14], [15]
Legal Expenses	Capital investment	As per the *Peter et al.* model [11]	1.14	Ratio between labour costs for lawyers in IT [19] and CZ. [20]
Engineering/Construction Contractor's fee	Capital investment	As per market fees in CZ	n.a.	n.a.
Contingency	Capital investment	Chosen value – a low value of 5% was chosen due to high confidence in estimates backed by industrial reality at the time the study was performed	1.2	The average of conversion factors applied to any entries, that range from 1.00 to 1.79
Raw materials	Materials & Labour	Based on data acquired from an inquiry procedure conducted in the CZ in the middle of 2023	0.85 €/kg Used Cooking Oil	Survey CONOE associates - Feb 2023
Operating Labour	Materials & Labour	The hourly rate was chosen according to average salary in Moravian-Silesian (CZ), in the middle of 2023	20.83 €/h	The operator hour rate in Italy is calculated by dividing the estimated labour costs for shift labour (3000 €/month), divided by the average amount (144) of working hours/month
Process Air, Instrument Air Prices	Utilities	The costs were calculated as (solely) electricity spending for compressor operation, i.e. included in the electricity item	n.a.	n.a.
Electricity	Utilities	Prices in CZ, in the middle of 2023	0.134 € / KWh	Price of electricity for industry in Italy [21], [22]
Natural Gas	Utilities	Prices in CZ, in the middle of 2023	30.65 € / K	Price of Natural Gas in Nov 2023
Non-hazardous waste disposal	Utilities	As per budgetary information, in CZ, 2023	0.110 € / Kg	Average from various waste management companies.
Process Water	Utilities	The total costs per cubic metre as per listed prices in Ostrava, CZ, in the middle of 2023	0.03440 €/Kg	Water prices ACEA [2023] (it includes sewage services and aqueduct usage fee) [23]

Table I - Continues

Data type	Specificities for P3HB production plant against a chemical plant (Czech case)		Conversions for the Italian case (Dec 2023)	
	location in the calculation sheet	**Rationale for the specificity**	**Conversion factor or direct cost**	**Rationale behind the change**
Operating Supervision Costs	Annual TPC	Calculated using the estimated respective technology needs, used an average salary on such a position in Moravian-Silesian Region of CZ, in the middle of 2023	n.a.	n.a.
Maintenance & Repairs cost coeficient	Annual TPC	Value was established by technology type and chosen according to Roušar (2008) [13]	n.a.	n.a.
Operating supplies	Annual TPC	As per Nafigate company internal estimates	n.a.	n.a.
Laboratory Staff	Annual TPC	The numbers were estimated combining the amount of personnel needed by the respective technology,	28'500 €/y	Average gross salary for a quality control technician
Process and Quality Analyses Lab	Annual TPC	Technology provider's internal knowledge of analyses costs are used	n.a.	n.a.
Quality Control [QC] staff	Annual TPC	The numbers were estimated combining the amount of personnel needed by the respective technology,	40'000 €/y	Average gross salary for a quality control supervisor
Property Tax	Annual TPC	Estimated average of property tax rate applied in CZ in 2023	0.00 €/m^2	From 2023, in Italy the property tax on estates (IMU) is fully deductible for industrial buildings
Financing – interest rate	Annual TPC	A value obtained in a 2022 R&D project was used.	n.a.	The interest on loans is similar for the two countries (4,5%)
Insurance	Annual TPC	Value was thougt by technology type and chosen according to Roušar (2008) [13]	n.a.	n.a
Rent	Annual TPC	The specific value per unit area from a 2022 R&D project was used and multiplied by area required for the respective technology unit.	n.a.	n.a
Plant overhead, general	Annual TPC	Project-specific internal estimate,		
Cost of Scraps	Annual TPC	Estimated as as 5% of variable costs	n.a.	n.a
Administration	Annual TPC	Calculated using estimate of number of human resources needed and multiplied by respective average salaries on such positions in CZ, 2023	n.a.	The model estimates these values from labour costs (already updated)
Distribution & Selling	Annual TPC	Calculated using estimate of number of human resources needed and multiplied by respective average salaries on such positions in CZ, 2023	n.a.	The model estimates these values from labour costs (already updated)
Construction, product price, and TPC inflation rates	Evaluation	Industry long-term expectations in early 2023, in CZ	n.a.	n.a
Income tax rate	Evaluation	21% used as CZ relevant value from 2024 onwards	n.a.	n.a
Minimum acceptable rate of return	Evaluation	Set on 8% as minimal value considered by investors during long-term discussions	n.a.	n.a

3. RESULTS AND DISCUSSION

The following section reports the results and the discussion of the three consecutive evaluation steps of a P3HB production plant that uses UCOs as feedstock in Italy, that is, the technical feasibility, the OPEX calculation and the economic feasibility.

3.1. CHEMICAL PHYSICAL ANALYSIS

Table II presents the characterization of two samples of UCOs collected from households in the Lazio Region, one crude (not treated according to the Italian framework for the conversion of collected UCOs into secondary raw material for recycling processes) and the second treated according to the aforementioned regulatory framework in order to obtain end-of-waste status for conversion into a secondary raw material. Table II also presents the reference value ranges suggested by the technology provider.
Acid Value is a measure of triglycerides hydrolysed into free fatty acids (FFA) and glycerol. While a certain amount of FFA in the oil is beneficial for the P3HB production process, process yield may be reduced over a limit of 150 mg KOH / g. The Acid Value for crude samples corresponds to degraded cooking oils and, although slightly higher than usual in Europe, they would probably perform well in the fermentation process, given the robust nature of the process against this parameter. The treated oil has slightly reduced acidity due to the water separation process it undergoes in order to remove part of the amphiphilic free fatty acids.
The saponification value is a measure of the average chain length of the fatty acids in the sample in the form of glycerides. The values recorded indicate a slight shortening of the chains after treatment, with no negative effects on the conversion process. The values for both samples are in the same range as oils like olive oil and canola oil, which indicates that the oils are suitable to effectively undergo the fermentative process.
As with the iodine values, both samples lie within a range corresponding to “non-drying oils” (i.e. oils that do not polymerize in presence of oxygen and so do not create solid films). The iodine value is an important way of measuring unsaturation in fats and oils. Double and triple bonds in fatty acid chains reduce energy content while boosting polymerization. The amount of unsaturation demonstrated by the measured value implies that the characterised oils are not likely to polymerize on the surface of reactor components such as valves, sensors, etc. thereby limiting the occurrence of related process setbacks. Considering that bacteria metabolise only unpolymerized UCOs, this reduced tendency to polymerization also means reduced losses of substrate that can be used for fermentation during long-term storage of the oil.
The peroxide value is a measure of fat oxidation. The measured low values for both samples indicate low levels of rancidification and therefore a lower level of oil deterioration that would otherwise lead to limited process yields.
The content of the aqueous phase must be less than 3% in weight before introducing the UCOs in the fermenter. The crude sample does not comply with this requirement, but water can be removed with a simple physical treatment. It is worth considering that this removal would be achieved through the installation of a UCO pre-treatment unit.
Even though both crude and treated oils from the Lazio region are potentially suitable for fermentation and conversion into P3HB, the authors consider the best choice to be treated oils since they facilitate the attainment of end-of-waste status, making it easier to obtain environmental permits for the plant installation and operation.

3.2. OPEX CALCULATION AND CAPACITY PRODUCTION SELECTION

OPEX calculations were performed for different production capacities and are presented in Table III. The production plant scenario is expensive due to its biotechnological nature, and draws little benefit from economies of scale since production units are modular. The bigger the plant, the higher the number of biological reactors that must be installed. This is reflected in the OPEX for plants of different capacities, which still decreases even after doubling already significant production capacities. On the other hand, the modular

Table II - Chemical physical analysis (in duplicates) of Italian samples of used cooking oils from households

Characterization item	Italian sample, crude [average of 2 replicates]	Italian Sample, treated [average of 2 replicates]	Reference values as suggested by the biotechnology provider
Acid Value [mg KOH / g]	7,6 ± 0,1	4,9 ± 0,1	0,5-150
Saponification Value [mg KOH / g]	180 ± 3	192 ± 1	120-220
Iodine Value [g I_2 / 100 g]	74 ± 1	75 ± 2	15-130
Peroxide value [µmol O_2 / kg]	6 ± 0.4	12 ± 0.4	0-300
Content of aqueous phase [% by weight]	~ 20%	~1.5	< 3 %
Solids [% by weight]	< 1 %	< 1 %	< 1 %

Table III - OPEX for three different plants, depending on production capacity [EUR, converted from Czech market]

Cost item	OPEX [EUR / Kg P3HB]		
	35 t/y	175 t/y	350 t/y
Material costs for fermentation and isolation	3,060	3,200	3,154
Labour	12,615	4,931	2,718
Energy	7,881	6,026	5,948
Waste disposal at an anaerobic digestion plant	2,385	2,132	2,078
Maintenance and other costs	1,919	1,246	1,045
Site Rental	7,470	0,889	0,611
Quality control (laboratory consumables)	1,173	0,586	0,586
Corporate civil liability insurance	0,640	0,415	0,697
Scrap costs	1,828	0,985	0,868
Total OPEX	38,971	20,410	17,705

layout makes it possible to easily expand operations while retaining existing facilities.
Considering that the business to business (B2B) market value of P3HB as an ingredient in cosmetics applications is 40-55 €/kg, the construction of a 35 t/y capacity production plant would not be viable for a profitable business. A small-scale operation would only be attractive if supported by grants and/or funds, or if the production process is aimed at a biomedical application with a higher value (above 90 €/kg). Production capacities of 175 t/y and 350 t/y must be the target if a profitable business is to be created for the production of P3HB as an ingredient in cosmetics applications. In the following section, we demonstrate that, in the Italian case, a production capacity of 350 t/y, with an initial two-year period of halved production capacity (175t/y), would be a potentially profitable business opportunity.

3.3. ECONOMIC FEASIBILITY

Based on the considerations in section 3.1, we modelled production plants with feedstock of treated used cooking oils. Costs linked to the procurement of this secondary raw material were considered and the absence of a dewatering pre-treatment unit in the plant was assumed. This model is referred to in the OPEX evaluation in section 3.2.
For a plant located in Italy, the model gives an average yearly return on investment (ROI) of ~14.5%, with a payback period of 4.1 years. These are quite good values for the chemical industry in manufacturing raw material for further production. A conservative estimate of a 6% inflation rate was used in the model and, if the European economy remains stable, the profitability indicators would be even more advantageous.
In order to identify production costs that might disrupt the project‘s economic feasibility, we analysed the weight of each production cost on the TPC. As shown in Figure 1, the cost categories that most affect TPC are financing (17.9%), input materials (17.0%), labour (15.5% - both in operations and oversight) and maintenance and repairs (13,7%).

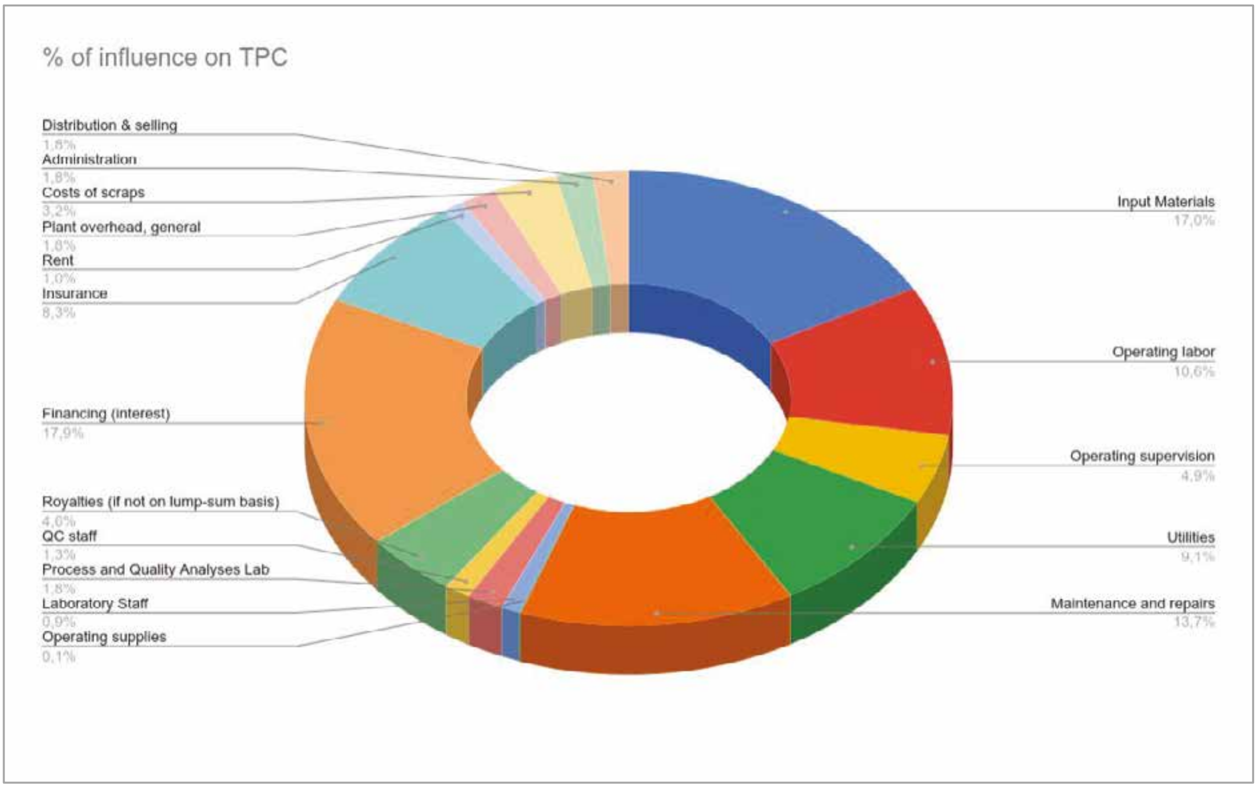

Figure 1 - TPC share among the different cost categories

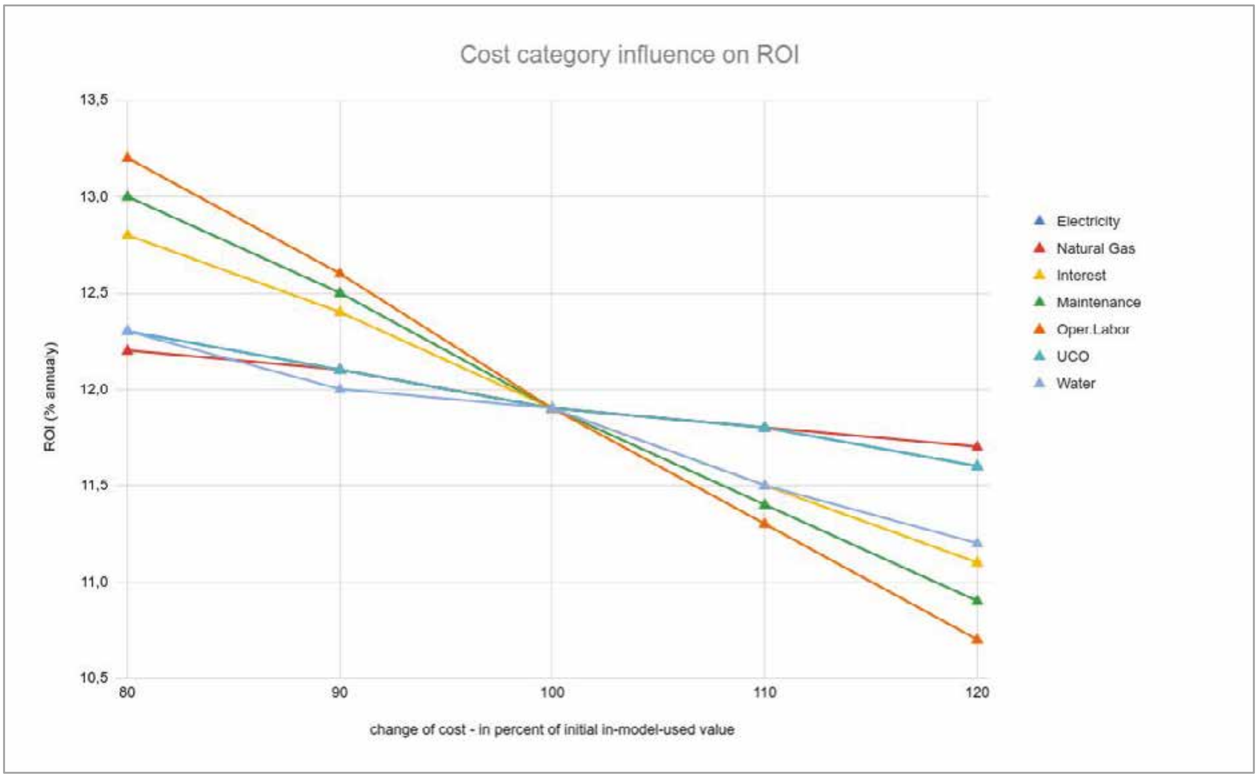

Figure 2 - Graph of impact of proportional changes of selected items on ROI (% yearly average)

A closer examination of the cost category "input materials" shows that UCOs and water make up 70% of the cost item (i.e.: 11.9% of total TPC) while the commodity items mentioned in Section 2.3, if taken individually, have lesser significance. Rising inflation, however, as in the last few years, can affect all prices and disrupt the weight factors of cost categories, reducing net return and profitability. Among the process inputs, electricity and natural gas are also significant. The increasing costs of electricity and gas may therefore also disrupt the economic model. To reduce the sensitivity of the model to energy market fluctuations in 2023, the authors drew on costs from late 2022, when energy costs hit record prices.

After identifying the cost categories with greatest impact on TPC, an assessment of the cost items' impact was performed by modifying in turn the value of the items with greatest weight on TPC (ranging from 8% to 20%) to values equivalent to 80%, 90%, 110% and 120% of the original default value. To this end, the most relevant subcategories were extracted from the significant categories of Utilities and Material Inputs and submitted for assessment together with Operating Labour, Maintenance and Interest. These are Electricity, Natural Gas, Used Cooking Oil (UCO) and Water. The results are presented in Figure 2.

The cost categories with the least impact are Electricity, Natural Gas, UCO and Water. Operating Labour Costs, Maintenance and Interest have the greatest impact, in that order.

Maintenance rates are, for the most part, an estimate for the new technology and do not usually vary much with the fluctuations of the economy and so Operation Labour Costs is the most significant cost category to be taken into account when choosing the right site for the plant in Italy. The lowest possible interest rate must be obtained from the banks or the amount of the loan required reduced, for example, by seeking as much equity investment as possible. The rest of the cost categories have much less significance and can be omitted in initial stages of site selection, to be used for later for the optimization of the plant site economy.

4. CONCLUSION

The authors conclude that the samples of UCOs collected from households in the Lazio Region are suitable as feedstock for the Hydal® biotechnology that produces P3HB as an ingredient used in cosmetics applications, with a B2B market value starting at ~50 €/kg for the lowest product grades. The authors suggest consideration of the treated used cooking oils available on the secondary raw material market rather than crude, collected but untreated oil. As well as improved performance in the fermentation process, treated UCOs are useful for obtaining end-of-waste status, thereby making it easier to obtain environmental permits for the plant installation and operation.

When it comes to production capacity, financial indicators like OPEX, ROI and payback period show that 350t/y, with an initial two-year period of halved

production capacity (175t/y), is a potentially sound business opportunity, with an average yearly ROI of 14,5% and with a payback period of 4.1 years. However, the authors are aware that the market for P3HB for cosmetics applications in Italy is not yet sufficiently mature to sustain the business case.
Market fluctuations in the demand and supply sides were considered in order to check the robustness of the Italian case. Although significant fluctuations in the cost of treated UCOs, electricity and natural gas, barely affect OPEX or other financial indicators, rises in Operation Labour Costs and Interest rates would affect the profitability of the business if the P3HB selling price remains unchanged.
However, the very favourable market outlook for P3HB as an ingredient for use in cosmetics applications and the current and future EU legislative framework are very positive. [7]–[10] The relevant cosmetics segments for P3HB-based products are forecast to enjoy strong growth, namely upcycled cosmetics ingredient 6.5% CAGR, waterless cosmetics 9,6% CAGR, UV protection 9.1% CAGR and Natural and Organics cosmetics of 9.5% CAGR. Overall, these markets were worth more than 60 billion euros in 2024. [24]

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