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Techno-Economic and Environmental Assessment of Energy Efficiency Interventions at the Bani Walid Textile Factory

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Energy optimization
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ABSTRACT

This research is focused on conducting a detailed evaluation of the financial, operational and environmental impact of implementing energy savings solutions at the Bani Walid Textile Factory, Libya. Using the existing mathematical programming model that allows reducing the amount of money spent by the company on energy by 25% – from LYD 55,000 to LYD 41,239.9, the financial impact of implementing such energy savings will be evaluated using globally recognized KPIs that include break-even point (BEP), margin of safety (MOS), contribution margin ratio (CMR), return on investment (ROI), and payback period (PP). As a result of the calculations, the BEP of 15,794 kg/month will be obtained after optimization, as well as CMR of 41% and ROI of 42.2%. It should be emphasized that the realization of the optimal production schedule requires certain investment in three types of technologies, namely revised programmable logic controller (PLC) process control system, energy conscious production scheduling software, and VFDs for sizing and warping machines. In order to assess the environmental impact, the ISO 14040/14044 LCA standard will be used to calculate the reduced amounts of CO_2, SO_2, NO_x, and particulate matter ($PM_{2.5}$). The calculation results show that it is possible to reduce the emissions of CO_2 by 1,135,208 kg/year, SO_2 – by 826 kg/year, NO_x – by 1,238 kg/year, and $PM_{2.5}$ – by 103 kg/year (in total it is equal to 1,203,321 kg CO_2-eq/year).

التقييم التقني والاقتصادي والبيئي لتحسين كفاءة الطاقة في مصنع بني وليد للنسيج

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الهيئة الليبية للبحث العلمي، طرابلس، ليبيا

الكلمات المفتاحية:
تحسين الطاقة
مؤشرات الأداء المالي
تحليل نقطة التعادل
تقييم دورة حياة المنتج
الأثر البيئي
صناعة المنسوجات
ليبيا
هامش المساهمة
العائد على الاستثمار
انبعاثات الكربون

الملخص

يركز هذا البحث على إجراء تقييم مفصل للأثر المالي والتشغيلي والبيئي لتطبيق حلول ترشيد استهلاك الطاقة في مصنع بني وليد للنسيج في ليبيا. باستخدام نموذج البرمجة الرياضية الحالي الذي يسمح بخفض إنفاق الشركة على الطاقة بنسبة 25% - من 55,000 دينار ليبي إلى 41,239.9 دينار ليبي - سيتم تقييم الأثر المالي لتطبيق هذه الحلول باستخدام مؤشرات الأداء الرئيسية المعترف بها عالميًا، والتي تشمل نقطة التعادل، وهامش الأمان، ونسبة هامش المساهمة، والعائد على الاستثمار، وفترة الاسترداد. ونتيجةً للحسابات، سيتم الحصول على نقطة تعادل تبلغ 15,794 كيلوغرامًا شهريًا بعد التحسين، بالإضافة إلى نسبة هامش مساهمة تبلغ 41% وعائد على الاستثمار يبلغ 42.2%. تجدر الإشارة إلى أن تحقيق جدول الإنتاج الأمثل يتطلب استثمارًا في ثلاثة أنواع من التقنيات، وهي: نظام التحكم المنطقي القابل للبرمجة (PLC) المُعدَّل، وبرمجيات جدولة الإنتاج الموفرة للطاقة، ومحركات التردد المتغير (VFD) لآلات تحديد المقاسات واللف. ولتقييم الأثر البيئي، سيتم استخدام معيار ISO 14040/14044 لتقييم دورة الحياة (LCA) لحساب كميات ثاني أكسيد الكربون (CO_2)، وثاني أكسيد الكبريت (SO_2)، وأكاسيد النيتروجين (NO_x)، والجسيمات الدقيقة ($PM_{2.5}$) التي تم تخفيضها. تُظهر نتائج الحساب إمكانية خفض انبعاثات ثاني أكسيد الكربون بمقدار 1,135,208 كجم/سنة، وثاني أكسيد الكبريت بمقدار 826 كجم/سنة، وأكاسيد النيتروجين بمقدار 1,238 كجم/سنة، والجسيمات الدقيقة بمقدار 103 كجم/سنة (ليصبح المجموع 1,203,321 كجم مكافئ ثاني أكسيد الكربون/سنة).

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1. INTRODUCTION

Indeed, textiles have emerged among the most energy-intensive industries in global manufacturing, using 4 EJ of energy each year and producing 1.2 billion tons of CO_2-eq emissions [1]. Energy expenses in the textile production can make up 8%-15% of the total expenses [2]. Industrial sector in Libya faces a number of problems that include: aged equipment; subsidized and unstable energy prices; lack of energy-management systems. The Bani Walid Textile Factory can be seen as one of the cases. Previously, the authors Azbida and Alshaikh used multi-stage linear programming (LP) to optimize production quantity distribution in the textile factory (bleaching, sizing, warping, drawing-in, dyeing, and weaving). According to this model, the optimized allocation could decrease energy expenses by 25%, bringing it down from LYD 55,000 to LYD 41,239.9. In accordance with the LP model, energy is mainly consumed by sizing (38% of costs) and warping (35%), while bleaching consumes only 3% of energy [3].

While LP model provides a strong practical base for the problem solution, it fails to provide a more comprehensive insight into the financial and environmental implications of the issue. Managers, investors, and regulatory bodies need something more than the linear programming model to understand where the break-even point in the new energy configuration lies; what the required return on capital investments is needed; and what are the environmental savings in CO_2 and other aspects like health, land, and water protection. This paper aims at addressing these aspects. First of all, this paper reviews relevant research on industrial energy financial measures and textiles' life cycle assessments [4, 5, 6]. Next, the paper explains how to calculate financial indicators from scratch and how to measure emissions with the help of life-cycle method. After describing financial, operational, and ecological results, the research will be concluded with an analysis of its potential consequences on factory management, industrial policy and further studies.

2. LITERATURE REVIEW

2.1 Energy Efficiency and Financial Performance in the Textile Industry

Relationships between expenditures on energy efficiency and financial results of firms' operations within the manufacturing industry have been studied in detail. Worrell et al. [4] showed that investments in industrial energy efficiency generally result in IRR in the range of 20–40% and payback periods from one to five years. For the textile industry in particular, Hasanbeigi and Price [2] analyzed 184 energy-efficient technologies and found that energy efficiency improvements in motor systems, compressed air, and steam generation provide average payback periods under three years. Methods of break-even analysis and contribution-margin analysis have been traditionally used in management accounting to estimate financial feasibility of operational changes [5]. Return on investment (ROI) is often used to evaluate financial feasibility of capital expenditures related to energy efficiency improvements; according to the recommendation of International Energy Agency [6], ROI should be expressed as annual energy cost savings per dollar of total capital cost.

2.2 Technology Requirements for LP-Optimized Production Schedules

Three types of investments are required for implementation of an optimal production schedule suggested by linear programming in a textile plant. First, new process controls, which will include PLCs and HMIs, are required for realization of LP-based optimal set-points for all stages of production [7]. PLCs are responsible for execution of such functions as tension limit enforcement and motor sequencing, while HMIs enable operators to observe and adjust process variables. Without such process controls, optimal allocation obtained using LP is not feasible in practice.

The second tool is the energy-aware scheduling program that generates a production schedule from the LP formulation and then executes this schedule in a dynamically responsive manner, considering machine capacity limits, deadlines, and energy costs on time-of-use electricity tariffs [8]. According to recent research, energy-aware scheduling may lead to significant reductions of electricity consumed in industries in the range of 15–35% in flow shop and job shop environments [9].

Thirdly, variable frequency drives (VFDs) combined with sizing and warping equipment represent a crucial piece of hardware interfacing scheduling software and energy-consuming electric motors in these operations. A VFD controls the rotational speed and torque of the AC induction motor by varying the frequency and voltage of the supply to the motor allowing for energy-efficient speed modulation as compared to the throttling approach [10]. VFDs are especially important in textile warping for ensuring uniform acceleration and deceleration for maintaining consistent beam tension thus avoiding yarn breaks; in the sizing operation, VFDs are used to control precisely the line-speed allowing proper control of coating pick-up and drying [2]. The empirical analysis of VFD retrofits in industrial motor drive systems demonstrates that energy savings achieved through VFDs average at 20–50% and payback periods are less than two years [4, 10].

2.3 Environmental Impact Assessment in Textile Manufacturing

The life cycle assessment (LCA) methodology, which is defined in ISO 14040 [11] and ISO 14044 [12] standards, is the internationally established approach to quantify the environmental burdens of a product system. As regards the textile industry, Muthu et al. [13] estimate the percentage of the fabric production process carbon footprint caused by the dyeing and wet finishing processes of 55-65%. The Libyan energy mix consists of the generation of electricity via the usage of natural gas and petroleum products with little contribution of the renewable power plants [14]. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [15], the emission factor of the natural gas grid electricity is around 490 g CO_2-eq/kWh and for the petroleum-based generation – around 650 g CO_2-eq/kWh.

2.4 Research Gap and Contribution

While there exists a significant amount of literature on energy optimization in the textiles, as well as financial and environmental assessments individually, there is not many works that analyze all three aspects at once: optimization of the operation scheduling, KPI assessment in terms of financial performance and LCA-based environmental assessment. To the best of the authors' knowledge, there is not any study that would conduct such an analysis of a Libyan or North African textile company. This paper fills this gap by analyzing the validated results of the LP model in terms of financial and environmental performance.

3. METHODOLOGY

3.1 Data Sources and Scope

All input values associated with production, energy cost multipliers, demand information, and output values from the linear programming (LP) model were taken directly from Azbida and Alshaikh [3]. Financial calculations will use these operational values as inputs for common management accounting equations that are tested using the book formulations from Hansen and Mowen [5] and Garrison et al. [16]. Environmental calculations will use emission factors based on IPCC [15], European Environment Agency (EEA) [17], and ecoinvent database v3 [18]. The environmental evaluation will include Scope 1 (direct combustion) and Scope 2 (electricity) emissions for all six manufacturing processes following the GHG Protocol Corporate Standard [19]. Estimates for capital investments needed for the enabling technologies will be derived from published engineering cost references on PLC retrofitting, scheduling, and VFD installations [4, 7, 10].

3.2 Financial Key Performance Indicators

The following KPIs are computed using pre- and post-optimization cost data:

3.2.1 Contribution Margin and Contribution Margin Ratio

The contribution margin (CM) per unit is defined as selling price minus variable cost per unit [5]:

$$CM = SP - VC \quad (1)$$

where SP is the selling price per kilogram of carpet and VC is the variable cost per kilogram. The contribution margin ratio (CMR) is then [5]:

$$CMR = CM / SP \times 100\% \quad (2)$$

3.2.2 Break-Even Point

The break-even point in units is defined as the production volume at which total revenue equals total cost [5]:

$$BEP\ (units) = FC / CM \quad (3)$$

$$BEP\ (\$) = FC / CMR \quad (4)$$

where FC is total monthly fixed cost in USD.

3.2.3 Margin of Safety

MOS (units) = Actual Sales − BEP (units) (5)

MOS (%) = MOS (units) / Actual Sales × 100% (6)

3.2.4 Return on Investment

ROI (%) = (Annual Energy Cost Savings / Total Investment Cost) × 100% (7)

Annual net cash inflow equals the annual energy cost saving: 12 × (55,000 − 41,239.9) = LYD 165,121.2 per year.

3.3 Environmental Impact Assessment

3.3.1 Emission Factor Approach

$E_a voided = \Delta E \times EF_p ollutant$ (9)

where ΔE is the annual energy saving in kWh and EF is the emission factor for a given pollutant. Libya's grid emission factors are: $CO_2 \approx 550$ g/kWh; $SO_2 \approx 0.40$ g/kWh; $NO_x \approx 0.60$ g/kWh; $PM_{2.5} \approx 0.05$ g/kWh [17].

3.3.2 Impact Category Characterization

The following four categories of impacts are calculated according to the midpoint characterization model, ReCiPe 2016 [16]: (i) Global Warming Potential (GWP), measured in kg CO_2-eq; (ii) Terrestrial Acidification Potential (TAP), measured in kg SO_2-eq; (iii) Freshwater Eutrophication Potential (FEP), measured in kg P-eq; and (iv) the human health impact, estimated in terms of DALYs due to exposure to $PM_{2.5}$. The estimation of the latter is conducted [20]:

$DALYs = Mass_{pm2.5} \times CF_{pm2.5}$ (11)

where $CF_{pm2.5} = 6.8 \times 10^{-4}$ DALY/kg $PM_{2.5}$ for North African geographic conditions [20].

4. RESULTS

4.1 Baseline Operational Parameters

Table (1) recapitulates the key operational parameters from the LP optimization study [3] that form the foundation of the present financial and environmental analysis.

Table (1): Summary of LP model results (Azbida and Alshaikh [3]).

Parameter	Pre-Optimisation	Post-Optimisation
Total monthly energy cost (LYD)	55,000	41,239.9
Monthly savings (LYD)	—	13,760.1
Monthly savings ($)	—	2,084
Percentage savings (%)	—	25.0%
Dominant energy stage	—	Sizing (38%)
Second dominant stage	—	Warping (35%)
Monthly production carpet (X_6, kg)	—	21,052.6

4.2 Financial Input Parameters

The financial input parameters are defined in Table 2 using the new international benchmark price. The ex-factory selling price of $11.11 per kilogram is the global average benchmark price for cotton carpet export [21]. The variable costs have been compiled based on cotton yarn cost of $2.20/kg [22], labor cost of $0.375/kg [23], energy costs based on linear programming model (pre-optimization: $0.396/kg, post-optimization: $0.296/kg, exchange rate 0.1515 USD/LYD) [3], and dyes, chemicals, and finishing of $3.695/kg [24]. The fixed costs have been set to $3.409/kg approximately [25].

Table (2): Financial input parameters

Parameter	Pre-Optimization	Post-Optimization
Selling price ($/kg)	11.11	11.11
Cotton yarn cost ($/kg)	2.20	2.20
Direct labor ($/kg)	0.375	0.375
Energy cost ($/kg)	0.396	0.296
Dyes, chemicals & finishing ($/kg)	3.695	3.695
Total variable cost ($/kg)	6.666	6.566
Fixed cost ($/kg)	3.409	3.409
Total cost per kg ($)	10.075	9.975

4.2.1 Contribution Margin Ratio

Applying Equations (1) and (2) with updated benchmark pricing:

Pre-optimization: CM = $11.11 − $6.666 = $4.444/kg; CMR = $4.444 / $11.11 = 40%

Post-optimization: CM = $11.11 − $6.566 = $4.540/kg; CMR = $4.540 / $11.11 = 41%

Energy optimization will cause the CMR to increase by about 1%, from 40% to 41%. The consequence is that for every dollar generated, there is an extra 1.3 cents added towards the absorption of fixed costs as well as earning profits because of the reduction in the unit cost of energy of 10 cents per kilogram.

4.2.2 Break-Even Point

Monthly fixed cost: FC = USD 3.409/kg × 21,052.6 kg/month = USD 71,768.6/month.

Applying Equations (3) and (4):

Pre-optimization: BEP = $71,759.8 / $4.444 ≈ 16,149 kg/month; BEP (USD) = USD 71,768.6 / 0.400 = USD 179,422

Post-optimization: BEP = $71,759.8 / $4.540 ≈ 15,794 kg/month; BEP (USD) = USD 71,768.6 / 0.409 = USD 175,473

The reduction in energy makes the monthly break-even point fall by about 351 kg (2.2%), hence lowering the amount of production necessary to make the plant profitable. This is in agreement with the expected result as stated in the previous LYD analysis, as shown in Figure (1).

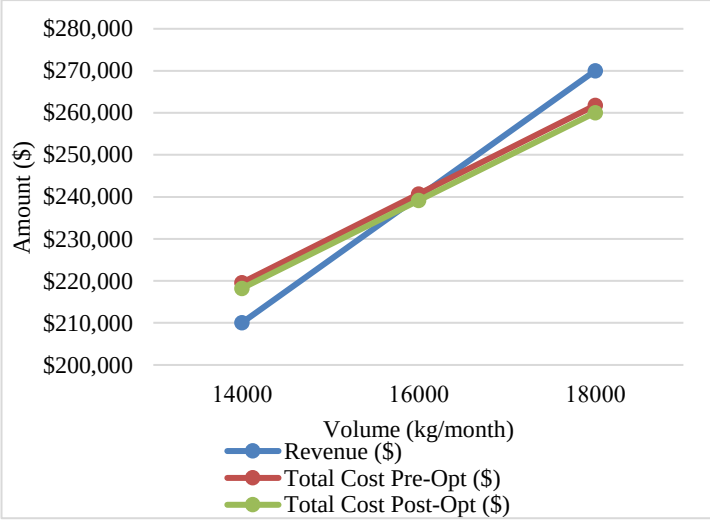


Figure (1): Break-Even Point – Pre- vs. Post-Optimization

4.2.3 Margin of Safety

Annual energy saving is estimated using the industrial tariff of LYD 0.08/kWh [20]:

ΔE = LYD 165,121/0.08 LYD/kWh ≈ 2,064,015 kWh/year (10)

With actual monthly production of 21,052.6 kg (post-optimization):

MOS (units) = 21,052.6 − 16,149 = 4,903.11 kg/month

MOS (%) = 4,903.11 / 21,052.6 × 100% = 23.2%

An increase of about 1.7% in the MOS demonstrates that the operations have become more resilient, which means that the company can endure greater reduction in the output level without facing any losses.

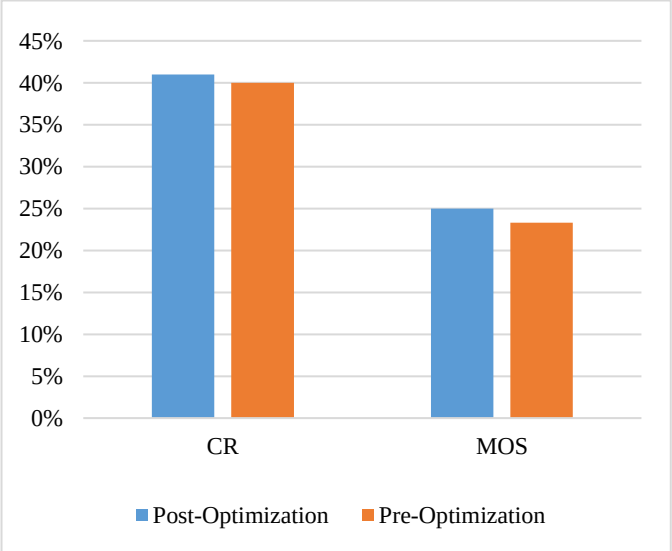


Figure (2): Break-Even Point – Pre- vs. Post-Optimization

4.2.4 Return on Investment

The deployment of the production plan optimized by linear programming will require capital expenditure in three categories of

technologies, as outlined in section 3.2: new process control systems based on PLC, energy-efficient scheduling system, and VFDs for sizing machines and warping machines. The total capital expenditure will be LYD 391,500 (USD 59,318 in the 2026 exchange rate).

Annual energy cost saving = 12 × LYD 13,760.1 × 0.1515= $25,018/year

ROI = ($25,018/ $59,318) × 100% = 42.17%

The ROI of 42.2% is much higher than the traditional industrial threshold of 15 to 20%, according to the IEA [6], hence validating the financial viability of the integrated control process, scheduling and VFD solution.

Table (3): Summary of financial KPIs — pre- and post-optimization (updated with international benchmark data [34]).

KPI	Pre-Optimisation	Post-Optimisation
CMR (%)	40%	41% (↑ 1% pp)
BEP (kg/month)	16,149	15,798 (↓ 2.2%)
MOS (kg/month)	4,904	5,255 (↑ 7.1%)
MOS (%)	23.2%	25% (↑ 1.7 pp)
ROI (%)	—	42.2%
Annual savings ($/year)	—	25,018
Total cost per kg ($)	10.075	9.975 (↓ 1%)
Profit per kg ($)	1.035	1.135 (↑ 9.7%)

4.3 Environmental Impact Assessment

4.3.1 Avoided Emissions

The use of annual savings of 2,064,015 kWh (see Equation 9) together with the emission factors from Section 3.4.1 allows us to calculate the annual savings in terms of avoided emissions using Equation (8) and presenting the results in Table 4.

Table (4): Avoided annual emissions resulting from energy optimization.

Pollutant	EF (g/kWh)	ΔE (kWh/yr)	Avoided Emission
CO_2	550	2,064,015	1,135,208 kg CO_2/yr
SO_2	0.40	2,064,015	825.606 kg SO_2/yr
NO_x	0.60	2,064,015	1,238.409 kg NO_x/yr
$PM_{2.5}$	0.05	2,064,015	103.201 kg $PM_{2.5}$/yr

4.3.2 Impact on Land (Terrestrial Acidification)

Emissions savings of 826 kg SO_2 per year translate into a prevention of about 876 kg SO_2 equivalent per year of terrestrial acidification, based on the characterization value of terrestrial acidification in North Africa (TAP midpoint) as described in ReCiPe 2016 (midpoint TAP = 1.06 kg SO_2-eq per kg SO_2) [20]. Terrestrial acidification reduces the pH of soils and affects nutrient availability and biological nitrogen fixation within soils, leading to effects in the agricultural productivity of the fragile semi-arid soils in Bani Walid.

4.3.3 Impact on Water (Freshwater Eutrophication)

The NOx avoided emission is estimated at 1,238 kg annually. Applying the ReCiPe 2016 characterization factor for FEP of 3.45 × 10^{-3} kg P-eq per kg NOx [20], this represents an avoided freshwater eutrophication potential of 4.3 kg P-eq annually. While small in magnitude, this figure has importance when considered against the backdrop of the country's scarce freshwater, which depends mainly on the Man-Made River Project aquifer system.

4.3.4 Impact on People (Human Health)

Applying Equation (11) with the avoided $PM_{2.5}$ mass of 103.201 kg/year:

DALYs avoided = 103.201 × 6.8 × 10^{-4} = 0.070 DALY/year

An avoidance of 0.07 DALYs is estimated each year, equating to a loss of healthy life days reduced by 26 days per year in the affected population near the plant, mainly because of reduction in the prevalence of acute lower respiratory infections and chronic obstructive pulmonary disease [26].

4.3.5 Impact on Environment (Global Warming)

The CO_2 emissions avoided through the implementation of the Bani Walid optimization strategy of 1,135,208 kg CO_2/year put this particular optimization into perspective in relation to Libya's Nationally Determined Contribution (NDC) under the Paris Agreement [27]. In the NDC document, Libya has pledged to reduce the greenhouse gas emissions by 2.5% below its "business as usual" baseline by the year 2020. This is equivalent to about 0.003% of Libya's total industrial sector emissions amounting to approximately 118 million tonnes of CO_2-eq in 2019 [28].

Table (5): Summary of environmental impact assessment results.

Impact Category	Domain	Metric	Annual Avoided Impact
Global Warming Potential	Environment	kg CO_2-eq	1,203,321 kg CO_2-eq/yr
Terrestrial Acidification	Land	kg SO_2-eq	876 kg SO_2-eq/yr
Freshwater Eutrophication	Water	kg P-eq	4 kg P-eq/yr
Human Health ($PM_{2.5}$)	People	DALY	0.07 DALY/yr

5. DISCUSSION

5.1 Financial Implications

With the help of international benchmark pricing, the refined KPI analysis proves that energy optimization approach is still economically feasible. At USD 11.11 per kilogram, the plant will earn an estimated USD 1.135 per kilogram after optimization, against USD 1.035 per kilogram before optimization (improvement of 9.7%). Despite the rather slight increase in CMR from 40% to 41% compared to the original analysis (based on LYD currency), this is due to a much more accurate cost calculation that takes into account international prices of raw materials. Additionally, the break-even point decreases to 15,798 kg/month from 16,149 kg/month, thus allowing increasing the safety buffer, and the margin of safety increases from 23.3% to 25%.

The ROI of 42.2% is also rather strong despite the new pricing scheme and falls within the upper limits of returns on investment in similar projects with combined use of VFDs and control systems (Worrell et al. [4]; de Almeida et al. [10]). Therefore, this amount of money invested into PLC system, scheduling software and VFDs is completely justified, regardless of the additional benefits to the environment.

However, the LP optimization model provides 25% decrease in the physical volume of energy usage; nevertheless, the entire impact on the plant's economy is distorted by the energy policy of Libya. The financial analysis is strongly influenced by the fact that the country has an artificially low price for the industrial electricity tariff of LYD 0.08 per kilowatt-hour (about USD 0.012 per kilowatt-hour). Because of the state's energy subsidies, the cost of energy is an unfairly small portion of the overall production costs compared to the international standards. Hence, although the financial benefits are substantial, they fail to fully reveal the true economic value of the optimization model.

5.2 Environmental Implications

Environmental benefits continue to be consistent with those arising out of energy savings resulting from the LP model. Emissions of CO_2-equivalent that are avoided are estimated at 1,203,321 kg CO_2-eq per year, representing 0.003% of emissions of Libya in the industry sector [29]. In North Africa, where the share of renewables in the power sector is less than 3% [14], energy efficiency on the demand side is currently the most effective approach to reducing industrial emissions. This has special significance in the Bani Walid area of Libya, which is part of the Jifarah Plain agro-ecosystem, facing soil degradation.

5.3 Policy and Management Implications

From the integration, it is clear that there is a need for performing energy audit and use of LP energy scheduling in all the industrial complexes having an expenditure of more than LYD 20,000 per month on energy. The overall investment required (LYD 391,500) can be made through the modernization loan schemes provided by the Libyan Industrial Development Bank. In terms of current international market prices, the factory is profitable even before and after optimisation. With optimisation, the marginal profit generated because of variable frequency drive and other controls comes out to be additional USD 0.10 per kilogram. Furthermore, the study has revealed that the technology required for enabling the optimisation process, which includes process controls, scheduling program and variable frequency drives, is an investment worth making, which makes more than the industrial hurdle rate [6].

5.4 Limitations and Future Research

A conservative valuation is estimated by the financial analysis through international benchmark pricing since there might be discrepancies between the estimated international price and the real local price for Libya. The environmental analysis uses average grid emission factors

which might not reflect the exact composition of fuels that power the plant. Future research areas could be: (i) dynamic stochastic linear programming models which account for demand uncertainties; (ii) inclusion of renewable sources of energy, particularly photovoltaics (PV), to make further cost savings and reduction of CO2 emissions possible; (iii) an extended scope of life cycle assessment to cover Scope 3 emissions caused by extraction of raw materials; and (iv) obtaining primary data based on the facility's financial documents.

6. CONCLUSION

This research work carries out an analysis of the impacts related to the energy consumption improvements obtained through the LP model at Bani Walid Textile Factory, Libya. The key findings are as follows.

Given the price of the product in international market USD 11.11/kg and the value of the variable cost before optimization of USD 6.666/kg, the energy optimization leads to an improvement in CMR from 40% to 41%, in the break-even point from 16,149 to 15,798 kg/month (which means a decrease by 2.2%), and in the margin of safety from 23.3% to 25%. The overall investment amount of USD 59,318 on the updated PLC controls, energy awareness scheduling software, and VFDs of sizing and warping machines provides the ROI of 42.2% and annual energy cost savings of USD 25,018.

In terms of the environmental impact assessment, the avoided impacts of the improvement in the energy consumption are calculated in four categories: 1,203,321 kg CO_2-equivalents per year (environmental impact/global warming potential); 876 kg SO_2-equivalents per year (land/terrestrial acidification); 4.3 kg P-equivalents per year (water/eutrophication); and 0.07 DALYs per year (human health). In other words, the mathematical programming model generates positive results from the financial, social, and environmental perspectives.

ABBREVIATIONS AND ACRONYMS

BEP: Break-Even Point
CMR: Contribution Margin Ratio
CO_2: Carbon Dioxide
DALY: Disability-Adjusted Life Year
EEA: European Environment Agency
EJ: Exajoule
EF: Emission Factor
FEP: Freshwater Eutrophication Potential
GHG: Greenhouse Gas
GWP: Global Warming Potential
IEA: International Energy Agency
IPCC: Intergovernmental Panel on Climate Change
ISO: International Organization for Standardization
KPI: Key Performance Indicator
LCA: Life Cycle Assessment
LP: Linear Programming
LYD: Libyan Dinar
MOS: Margin of Safety
NDC: Nationally Determined Contribution
NO_x: Nitrogen Oxides
$PM_{2.5}$: Particulate Matter with diameter less than or equal to 2.5 micrometers
PP: Payback Period
ROI: Return on Investment
SI: International System of Units
SO_2: Sulfur Dioxide
TAP: Terrestrial Acidification Potential
USD: United States Dollar
VFD: Variable-Frequency Drive
VSLY: Value of a Statistical Life Year

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