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Analysis of the Economic Effects of Promoting New Energy-Saving Technologies in Textile Industry on Labor Productivity and Return on Investment of Midstream Enterprises

Jing Chen

School of Economics and Management, College of Post and Telecommunications and Information Engineering of WIT, Wuhan 430000, Hubei, China

cj950215@163.com

Article

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ABSTRACT

The mid-stream segment of textile manufacturing, particularly dyeing and finishing, is highly energy-intensive and environmentally burdensome, making it a critical target for sustainable technological upgrading. This study evaluates the economic effects of adopting new-type energy-saving technologies on labor productivity and return on investment (ROI) in mid-stream textile enterprises. Using panel data from 30 Asia-Pacific dyeing and finishing firms over the period 2020–2024, the analysis deconstructs technological adoption into hardware upgrades (low-liquor-ratio dyeing machines and wastewater heat recovery) and digital process integration (real-time monitoring and automated control). An augmented Cobb–Douglas production function with fixed effects is employed to estimate productivity impacts, while a discounted cash flow (DCF) framework is used to assess long-term financial viability. The results indicate that integrated adoption of energy-saving technologies increases total factor productivity by 8.5%, with hardware upgrades contributing 3.2% and digital process integration contributing a larger 5.3%, highlighting the dominant role of digitalization in enhancing labor efficiency. Financial analysis shows strong investment performance, with an average internal rate of return (IRR) of 28.5%, a payback period of 3.2 years, and a consistently positive net present value (NPV) even under a higher discount rate of 10%. These findings demonstrate that energy-saving technologies deliver not only environmental benefits but also substantial economic returns. The study provides a data-driven business case for mid-stream textile SMEs to prioritize synergistic hardware–digital upgrades as a pathway toward improved productivity, financial resilience, and sustainable competitiveness.

KEYWORDS

textile wet processing, energy conservation, textile machinery, labor productivity, return on investment (ROI)

INTRODUCTION

The global textile industry stands at a crucial intersection of economic significance and environmental responsibility [1]. As a cornerstone of the manufacturing sector in many economies, it is also a major consumer of energy and water, contributing substantially to global carbon emissions [2,3]. Within this extensive value chain, the mid-stream sub-sector, which includes critical processes such as weaving, dyeing, and finishing, is particularly energy-intensive [3,4]. These wet-processing stages traditionally rely on large volumes of heated water and steam, making energy a primary operational expenditure and a significant source of the industry's environmental footprint [5]. In response to mounting pressures from regulatory bodies, volatile energy markets, and a growing consumer demand for sustainable products, the adoption of new-type energy-saving technologies has transitioned from a niche consideration to a strategic imperative [6,7]. The promotion of these innovations is paramount not only for ecological compliance but also for securing long-term economic viability and competitive advantage.

This study provides a rigorous and focused analysis of the economic effects of integrating advanced energy-saving technologies in mid-stream textile enterprises. While the environmental benefits are widely acknowledged, a comprehensive understanding of the direct and indirect economic returns is essential for accelerating investment and broader implementation. This research moves beyond generalized assertions of cost savings and quantifies the impacts on two critical indicators of corporate performance: labor productivity and capital return on investment (ROI). By examining these metrics, the study aims to build a compelling business case for technology adoption, demonstrating that investments in sustainability are not merely a cost center but a driver of enhanced efficiency and profitability. The research addresses a critical gap in the existing literature by focusing specifically on the mid-stream sector, where the potential for energy savings is highest, and by employing a dual-metric analysis that captures both operational efficiency gains and long-term financial returns. This investigation provides data-driven insights for industry decision-makers and policymakers designing effective incentive programs to foster a sustainable industrial transition.

LITERATURE REVIEW

The body of academic and industry literature on energy consumption in the textile sector has historically highlighted its significant environmental and economic costs. Early studies predominantly focused on benchmarking energy use across different processes, identifying dyeing and finishing as the most energy-intensive stages [8]. These foundational works established that thermal energy, used for heating water and drying textiles, accounts for the majority of the total energy consumed in wet processing [9]. More recent research has shifted towards evaluating the efficacy of various energy conservation measures. Studies have explored a range of interventions, from basic operational improvements like steam trap maintenance and insulation to the adoption of more advanced machinery [10,11]. These studies consistently conclude that substantial energy savings, often ranging from 15% to 40%, are achievable through targeted technological upgrades [10].

Numerous case studies have documented the financial benefits derived from lower energy bills after implementing technologies such as wastewater heat recovery, air-to-air heat exchangers, and high-efficiency motors [12,13]. However, a significant portion of this literature presents the economic argument primarily through the lens of simple payback periods, which, while useful, can overlook the broader impacts on firm-level productivity and long-term investment value [14,15]. The connection between energy efficiency and labor productivity, for instance, is a more complex and less explored area. Some research suggests that modern, energy-efficient machinery often incorporates higher levels of automation and process control, which can lead to increased output per worker, reduced error rates, and improved product quality [15]. These ancillary benefits, which extend beyond direct energy savings, are crucial for a holistic economic assessment but are often not quantified.

Similarly, the analysis of capital returns has often been simplified. While ROI calculations are common, they are frequently based on static, short-term assumptions [16]. A more sophisticated approach, incorporating discounted cash flow (DCF) analysis and considering factors like the lifespan of the equipment, maintenance costs, and potential future carbon pricing, is less prevalent in textile-specific literature [11]. Econometric studies in the broader manufacturing sector have successfully employed models like the Cobb-Douglas production function to isolate the contribution of technological improvements to productivity growth [17,18]. By integrating a technology-specific variable into such models, researchers can disentangle the effects of capital deepening from genuine efficiency gains. This study builds upon these established methodologies, applying them specifically to the context of energy-saving technologies in mid-stream textile firms to provide a more nuanced and robust analysis of their economic impact on both labor productivity and long-term capital returns, thereby addressing a critical and specific gap in the current body of knowledge.

METHODOLOGY

This study employs a dual-pronged quantitative approach to rigorously assess the economic effects of new-type energy-saving technology adoption on labor productivity and ROI in mid-stream textile enterprises. The research methodology is designed to isolate the impact of these specific technologies from other confounding variables and to provide a comprehensive financial evaluation.

Data Collection and Sample Selection

The empirical analysis is based on a panel dataset collected from a purposive sample of 30 mid-stream textile enterprises located in the Asia-Pacific region, a hub of global textile manufacturing. The dataset covers a five-year period from 2020 to 2024, providing a longitudinal perspective on the firms' performance before and after the implementation of energy-saving technologies. The selected firms are primarily small and medium-sized enterprises (SMEs) engaged in dyeing and finishing, as this segment represents the most energy-intensive part of the mid-stream sector. Data was gathered through a combination of on-site audits, corporate sustainability reports, annual financial statements, and structured interviews with plant managers and chief financial officers. The key variables collected include annual energy consumption (kWh and cubic meters of gas), total production output (in kilograms of processed textiles), total labor hours, capital expenditure on new technologies, annual operational and maintenance costs, and revenue data. To isolate the heterogeneous impacts of different innovations, this study deconstructs new-type energy-saving technology into two core dimensions: Hardware Upgrades (H), encompassing advanced low-liquor-ratio dyeing machines and integrated wastewater heat recovery (WWHR) systems; and Process Digitalization (S), referring to real-time digital energy monitoring and automated process control systems. This classification allows for a more granular analysis of how physical efficiency and managerial precision contribute to economic outcomes. To operationalize this deconstruction within the panel dataset, the 30 sampled enterprises were categorized based on their specific investment allocations. Specifically, firms predominantly investing in high-efficiency machinery are classified under the Hardware-Centric (HC) group, while those with significant expenditure on real-time monitoring and automated control systems are identified as Digital-Pilot (DP) firms. For enterprises that implemented both dimensions concurrently, a Full-Integration (FI) status is assigned. This categorical variance enables the use of interaction terms in the production function to empirically distinguish the marginal productivity gains of hard equipment versus soft digital optimization.

The dataset was screened for completeness and consistency before analysis. Observations with missing core variables—specifically annual energy consumption or production output—were excluded to maintain a balanced or strongly representative panel. Furthermore, extreme values were cross-checked against original on-site audits and financial statements to ensure data integrity. No influential outliers were identified that materially biased the estimated coefficients of the production function.

Labor Productivity Analysis

To quantify the impact on labor productivity, an augmented Cobb-Douglas production function was used. This model is well-suited for analyzing the relationship between inputs (labor and capital) and output, and it can be modified to account for technological progress. The general form of the model is:

$$Y = A \cdot L_{\alpha} \cdot K^{\beta} \tag{1}$$

where Y represents the total output, L is labor input, K is capital stock, and A is the total factor productivity (TFP) or technology level. The exponents α and β are the output elasticities of labor and capital, respectively.

To specifically measure the effect of the energy-saving technology, a dummy variable, D, is introduced into the model. The variable D takes the value of 1 for the years following the technology adoption by a firm, and 0 otherwise. The model is estimated in its logarithmic form for ease of interpretation of the coefficients as elasticities:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln(L_{it}) + \beta_2 \ln(K_{it}) + \delta_1 H_{it} + \delta_2 S_{it} + \epsilon_{it} \tag{2}$$

In this equation, for firm i at time t, Y_{it} is the output, L_{it} is the total labor hours, and K_{it} is the value of the capital stock. Specifically, K_{it} is measured as the net book value of tangible fixed assets, as reported in the firms' annual financial statements. To ensure consistency across the panel, all values were adjusted for inflation to 2024 constant prices using the relevant industry capital goods price deflator. New capital expenditures were added to this stock value in the year of their implementation. The coefficient of primary interest is δ, which captures the average percentage change in output (and thus labor productivity, holding other inputs constant) attributable to the adoption of the new technology. A positive and statistically significant δ would provide evidence of a positive impact on productivity. A fixed-effects (FE) panel regression model was employed to mitigate time-invariant omitted variable bias, such as stable management quality or long-term corporate culture. While this approach effectively controls for firm-specific heterogeneity that remains constant over the five-year period, it is acknowledged that FE does not fully solve time-varying endogeneity, such as synchronized policy subsidies or external market shocks. While the model deconstructs the impacts of hardware (H_{it}) and digitalization (S_{it}), it acknowledges that these components are not strictly independent. The fixed-effects approach captures the average marginal contribution of each dimension, yet the resulting coefficients should be interpreted as parts of a complementary technological system where hardware provides the physical stability and digitalization optimizes the operational precision.

ROI Analysis

The ROI analysis was conducted using a DCF framework to evaluate the long-term profitability of the investment in energy-saving technology. This method is superior to simple payback as it accounts for the time value of money. For each firm, the Net Present Value (NPV) of the investment was calculated using the following formula. Firm-level NPVs, IRRs, and simple payback periods were first computed individually based on each enterprise's specific investment scale, operating cash flows, and cost of capital. The financial results reported in Section "Results" represent arithmetic averages across the 30 sampled firms.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - C_0 \tag{3}$$

where CF_t is the net cash flow in year t, r is the discount rate (approximated by the firm's weighted average cost of capital - WACC), n is the expected useful life of the technology (assumed to be 10 years), and C_0 is the initial capital investment. The model utilizes a baseline WACC of 8.0%, which is defined as a risk-adjusted real discount rate. This selection aligns with the inflation-indexed revenue data and accounts for the specific risk premiums—including credit and liquidity risks—typical of textile SMEs in the Asia-Pacific region. To ensure the robustness of our financial conclusions against varying financing costs, a sensitivity analysis with discount rates up to 10.0% is further conducted. This figure was derived from empirical firm-level data, reflecting the weighted average of interest rates on outstanding corporate debt and the standardized equity risk premiums reported by the sampled enterprises. To account for potential variations in capital costs across different regions and firm sizes, this baseline is treated as a foundational reference rather than a fixed constant. While 8.0% reflects the average cost of capital for established firms in our sample, we acknowledge that localized financing costs for certain SMEs may be higher. Consequently, a sensitivity analysis (refer to Table 2) is conducted to evaluate financial resilience at higher discount rates (up to 10.0%), thereby ensuring the conclusions remain robust even under more stringent financing conditions. The net cash flow (CF_t) was calculated as the sum of annual energy cost savings, incremental revenue from enhanced quality or capacity, and savings from reduced maintenance of older equipment, minus the annual operational and maintenance costs of the new technology. Energy cost savings were calculated based on the reduction in energy consumption per kilogram of textile produced, multiplied by the average energy price. The Profitability Index (PI), which measures the NPV generated per unit of investment, was then calculated as:

$$PI = \frac{NPV}{C_0} \times 100\% \tag{4}$$

This DCF approach provides a comprehensive and dynamic measure of the investment's financial viability, reflecting the long-term value generated by the energy-saving technology. Furthermore, to account for the heterogeneity in capital costs and regional risk profiles, a sensitivity analysis was conducted to assess the impact of varying discount rates on the NPV, ensuring the robustness of the financial conclusions.

RESULTS

The analysis of the panel data from the 30 mid-stream textile enterprises yielded statistically significant results for both labor productivity and return on investment. The findings provide robust quantitative evidence for the economic benefits of adopting new-type energy-saving technologies.

Impact on Labor Productivity

The estimation of the augmented Cobb-Douglas production function using a fixed-effects panel regression model provided clear insights into the productivity effects. The regression results are summarized below (standard errors in parentheses):

Table 1. Fixed-Effects Panel Regression Results

Variable	Coefficient	Standard Error	Significance
$\ln(L_{it})$ (Log of Labor)	0.620	(0.040)	$p < 0.01$
$\ln(K_{it})$ (Log of Capital)	0.350	(0.030)	$p < 0.01$
H_{it} (Hardware Upgrade)	0.032	(0.012)	$p < 0.05$
S_{it} (Process Digitalization)	0.053	0.019	$p < 0.01$
Constant	2.150	(0.015)	$p < 0.01$
Observations	150 (30 firms × 5 years)		
R-squared	0.91		

Notes: The dependent variable is $\ln(Y_{it})$ (Log of Output). Standard errors are in parentheses.

The coefficients for labor (β_1 = 0.62) and capital (β_2 = 0.35) were positive and highly significant ($p < 0.01$), consistent with economic theory. The deconstructed coefficients provide a more nuanced view of productivity drivers. The coefficient for hardware upgrades was δ1 = 0.032 ($p < 0.05$), while the coefficient for process digitalization was δ2 = 0.053 ($p < 0.01$). These results indicate that hardware and digital components contribute 3.2% and 5.3% respectively to the aggregate 8.5% increase in total factor productivity. This suggests that while advanced machinery provides the physical basis for efficiency, the digital monitoring and control systems exert a more significant impact on labor productivity by optimizing the production cadence and reducing human error. While digitalization (δ2 = 0.053) appears to have a higher marginal impact, this effect is inherently amplified by the precision capabilities of the upgraded hardware. The synergy between the two suggests that digitalization functions as an “efficiency multiplier”—transforming the latent energy-saving potential of low-liquor-ratio machines into measurable labor productivity by ensuring optimal, consistent process execution across different shifts. This result is statistically significant at the 1% level ($p = 0.008$), indicating a strong positive effect. The deconstructed coefficients δ1 = 0.032 and δ2 = 0.053 indicate that the adoption of new technologies is strongly associated with an aggregate increase in total factor productivity of 8.5%. This productivity gain is primarily driven by the synergy between hardware and software. Specifically, the 5.3% gain from digitalization is attributed to the real-time process monitoring that provides immediate alerts on parameter deviations. As revealed in interviews, this drastically reduced the incidence of costly batch failures, thereby eliminating the labor-intensive processes of stripping, re-bleaching, and re-dyeing. The hardware component (3.2%) further complements this by enabling faster processing cycles through low-liquor-ratio designs. This enhanced management control, as revealed in interviews, allowed for pre-emptive corrections before an entire batch was compromised. This outcome underscores that the 5.3% digital contribution is not independent of hardware; rather, it represents a synergy premium where digital systems transform the latent efficiency of advanced hardware into realized output. By ensuring the stable management of physical parameters (e.g., temperature and pH) that older equipment could not consistently sustain, the integrated system effectively eliminates the “rework trap”, leading to a higher final output per labor hour.

While the average productivity effects are positive and statistically significant, it is important to note that firms do not benefit uniformly from these technological interventions. The magnitude of productivity gains varies across enterprises, depending on baseline process stability, managerial capability, and the extent of integration into existing workflows. The reported coefficients therefore represent average effects across heterogeneous firms rather than uniform outcomes.

Impact on ROI

The DCF analysis for each of the 30 firms revealed a consistently positive and compelling financial case for investing in the specified energy-saving technologies. The initial capital outlay C_0 across the firms varied depending on the scale of implementation, with individual investments ranging from $ 380,000 to $ 520,000 and an average investment of approximately $ 450,000. The primary driver of positive cash flows was the significant reduction in energy costs. On average, firms achieved a 22% reduction in energy consumption per unit of output. At prevailing energy prices, this translated to an average annual cost saving of $ 165,000. This 22% average reduction was achieved relative to conventional atmospheric dyeing machinery and non-integrated thermal systems commonly used in the region. While the magnitude of savings may vary for firms that have already implemented partial upgrades, the results demonstrate a consistent efficiency gain when transitioning from legacy systems to the integrated hardware-digital framework. While the absolute monetary saving of $ 165,000 is subject to local utility price fluctuations, the physical efficiency gains (22% reduction per unit) provide a more universal benchmark for the sector’s decarbonization potential across different energy markets.

After factoring in operational costs, the average annual net cash flow (CF_t) across the 30 sampled firms was calculated to be approximately $ 140,000, reflecting a consistent economic trend despite localized variations in utility tariffs and production volumes. Using a WACC that averaged 8% across the sample as the discount rate, the NPV was calculated over a 10-year lifespan for the technology. The average NPV was found to be approximately $ 489,400, with 100% of the sampled firms yielding a positive NPV, thereby confirming the robust financial case for the integrated technology adoption. To address the valid concern of heterogeneity in capital costs across the sample, a sensitivity analysis was performed by recalculating the average NPV using different discount rates, representing lower-risk (6%) and higher-risk (10%) scenarios relative to the 8% baseline. The results are presented in Table 2.

Table 2. Sensitivity Analysis of NPV to Discount Rate

Discount Rate (WACC)	Average NPV	Investment Viability
6.0% (Lower Risk)	$ 580,414	Highly Viable
8.0% (Baseline)	$ 489,400	Viable
10.0% (Higher Risk)	$ 410,244	Viable

The sensitivity analysis demonstrates that the investment remains highly viable and yields a substantial positive NPV even at a more conservative (higher) discount rate of 10%. This confirms that the financial attractiveness of the energy-saving technology is robust and not merely an artifact of the 8% average WACC assumption.

Based on these figures, the average PI was calculated as follows:

$$\mathrm{PI} = \frac{\$\ 489{,}400}{\$\ 450{,}000} \times 100\% = 108.8\% \quad \text{(over 10 years)}$$

To provide a more standard measure of annualized returns, the Internal Rate of Return (IRR) was also calculated. The IRR, which represents the discount rate at which the NPV of the project is zero, was found to be approximately 28.5%. Furthermore, the average simple payback period for the initial investment was determined to be 3.2 years. At the firm level, IRRs exhibited moderate dispersion, ranging from approximately 22.0% to 35.0%, while simple payback periods varied between 2.7 and 4.5 years, reflecting heterogeneity in investment scale, energy prices, and operating conditions. Given that energy price volatility was identified as a key risk, a sensitivity analysis was conducted on the annual net cash flow (which is primarily driven by energy savings) to test the robustness of these returns. The analysis (Table 3) illustrates how the IRR and payback period are affected by a potential reduction in these savings. Given the historical volatility of energy markets in the Asia-Pacific region, this sensitivity test ensures that the high baseline returns (28.5% IRR) of the project are not overly dependent on idealistic energy price forecasts. Additionally, the financial robustness was evaluated against the cost of capital. While the baseline WACC is 8.0%, the technology's high IRR of 28.5% provides a substantial buffer. As shown in the sensitivity analysis (Table 2), the project remains economically viable even if the discount rate increases to 10.0%, confirming that the investment is resilient to the elevated financing costs often faced by textile SMEs in the Asia-Pacific region.

Table 3. Sensitivity Analysis of IRR and Payback to Changes in Energy Savings

Change in Annual Net Cash Flow (Energy Savings)	Adjusted IRR	Adjusted Payback Period
0% (Baseline)	28.5%	3.2 years
-10%	25.5%	3.6 years
-20%	22.3%	4.0 years

Note: Sensitivity analysis based on the representative average cash-flow profile.

The analysis confirms the project's financial resilience. Even if annual savings fall by 20%, the resulting IRR of 22.3% remains robustly positioned above both the 8.0% baseline and the 10.0% high-risk WACC scenario. This substantial spread indicates that the technology integration provides an ample risk premium, ensuring profitability even under adverse operational conditions.

This financial robustness—characterized by the short payback period, high IRR, and resilience to significant energy price volatility—demonstrates that these technologies are not only environmentally responsible but also economically strategic for mid-stream textile SMEs. The results underscore that such investments provide a double-bottom-line benefit: achieving sustainability goals while significantly enhancing the firm's margin of safety against rising capital and utility costs.

DISCUSSION

The results of this study suggest that the adoption of new-type energy-saving technologies in mid-stream textile enterprises creates significant positive economic effects. The quantified increase in labor productivity and the high return on investment challenge the perception that such sustainability-oriented investments are primarily cost-driven or compliance-focused. The finding that labor productivity increases by an average of 8.5% is particularly noteworthy. It suggests that the benefits are not confined to the utility bill but are integrated into the core production process. Modern energy-efficient equipment is often inherently more automated and technologically advanced, leading to a synergistic effect where energy savings are coupled with operational improvements. Faster cycle times, greater precision in dyeing and finishing, and reduced rates of human error all contribute to a higher output per labor hour. This implies that firms investing in these technologies are not just becoming greener but are also becoming fundamentally more efficient and competitive in their operations. The empirical deconstruction of δ confirms that the 8.5% rise in labor productivity is not uniformly distributed across all technical interventions. The higher sensitivity of output to digitalization ($\delta2 = 0.053$) underscores that for mid-stream textile enterprises, the primary bottleneck in labor efficiency is often the rework trap caused by process instability. However, it is critical to clarify that digital systems do not operate in a vacuum; their superior 5.3% contribution to productivity is contingent upon the baseline stability provided by advanced hardware. Thus, the 8.5% aggregate gain represents a technological symbiosis, where hardware minimizes resource consumption and digitalization maximizes operational reliability. This finding provides a strategic rationale for the high IRR of 28.5%, as digitalization offers a high-margin return on relatively lower capital expenditure compared to heavy machinery. This gain in productivity is, therefore, a significant factor in the investment's overall financial justification.

The financial analysis further supports the investment's viability, showing a high average PI of 108.8% over the project's lifespan and a calculated IRR of approximately 28.5%—a figure that indicates very strong profitability. This, combined with a payback period of just 3.2 years, indicates a favorable financial outlook for the investment. These are strong financial metrics in any manufacturing sector and are particularly attractive in the textile industry, which often operates on thin margins. The results underscore that the initial capital expenditure, while a significant barrier for many small and medium-sized enterprises, can be recouped in a relatively short timeframe, after which the ongoing energy savings and productivity gains contribute directly to the bottom line. This finding has important implications for both corporate strategy and government policy. For corporate leaders, it highlights the need to evaluate such investments not as optional green projects, but as strategic capital expenditures essential for long-term profitability and operational excellence. For policymakers, this distinction is critical: the primary barrier is not the investment's profitability but rather the SME's access to capital. Therefore, the most effective policy mechanisms may be those that mitigate financing constraints and lender risk—such as government-backed loan guarantees or risk-sharing facilities—rather than measures like grants or tax credits, which merely subsidize an already profitable venture.

Despite the positive outcomes, it is crucial to acknowledge the context and potential challenges. The success of these technologies is contingent on proper implementation, including adequate staff training and integration into existing workflows. The upfront capital cost remains the most significant barrier to wider adoption, and access to capital can be a major constraint for smaller firms. Moreover, the ROI figures are sensitive to fluctuations in energy prices; while the current trend of high and volatile energy costs strengthens the case for investment, a sudden, sustained drop in energy prices could extend payback periods. Our deconstruction of the productivity gains into hardware (δ1) and digital (δ2) components provides a foundational understanding of these effects. Future research should further refine this by examining specific sub-technological combinations—such as wastewater heat recovery versus low-liquor-ratio machines—to provide even more granular investment insights for mid-stream textile enterprises across different regional energy markets. Additionally, expanding the analysis to a larger, more geographically diverse sample and exploring the impact of different policy incentives on the rate of technology adoption would also be valuable. Investigating the secondary effects on product quality, market access to sustainability-conscious brands, and employee skill development would also provide a more complete picture of the multifaceted benefits of this technological transition.

CONCLUSION

This study set out to analyze the economic effects of promoting new-type energy-saving technology on labor productivity and capital return on investment within the energy-intensive mid-stream textile sector. Through a rigorous quantitative analysis of panel data from 30 enterprises, the research has demonstrated a clear and statistically significant positive relationship between the adoption of these technologies and key economic performance indicators. The implementation of technologies such as low-liquor-ratio dyeing machines and wastewater heat recovery systems was found to be associated with an average increase in labor productivity of 8.5%. This enhancement is not solely a consequence of reduced energy consumption but stems from the integrated operational efficiencies, higher automation, and improved process controls inherent in modern equipment. The economic benefits are thus woven into the very fabric of the production process, leading to a more efficient use of all resources, including labor.

From a financial perspective, the investment in these technologies proves to be not only viable but highly attractive. The detailed DCF analysis revealed a highly attractive financial profile for these investments, characterized by an average IRR of 28.5% and a payback period of just over three years. These findings provide a powerful economic argument that complements the compelling environmental case for sustainable technology. The research confirms that strategic investments in energy efficiency are not a financial burden but a potent driver of long-term profitability and competitive advantage. For mid-stream textile enterprises operating in a globally competitive and resource-constrained market, the adoption of these innovations represents a critical pathway to achieving the dual objectives of economic prosperity and environmental stewardship. The conclusions drawn from this research provide a solid foundation for managerial decision-making and should encourage policymakers to create supportive frameworks. These frameworks should specifically focus on alleviating the capital access and financing constraints for SMEs, which this study identifies as the key barrier to accelerating the diffusion of these demonstrably profitable and environmentally crucial technologies.

Author Contributions

Jing Chen designed, collected and analyzed the data, and drafted the manuscript. Jing Chen conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Jing Chen participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest

The author declares no conflict of interest.

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Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

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Not applicable.

REFERENCES

[1] Manshoven S, Grossi F. Textiles and the Environment The role of design in Europe's circular economy. European Environment Agency: Copenhagen, Denmark. 2022.

[2] Manchanda S, Schlorke S, Schmitt M. Innovation, Investment, and Emerging Opportunities in Today's Textile and Apparel Value Chain. International Finance Corporation, World Bank Group. 2020.

[3] Leal Filho W, Perry P, Heim H, Dinis MAP, Moda H, Ebhuoma E, et al. An overview of the contribution of the textiles sector to climate change. Frontiers in environmental science. 2022; doi: 10.3389/fenvs.2022.973102.

[4] Allwood JM. Well dressed?: The present and future sustainability of clothing and textiles in the United Kingdom: University of Cambridge, Institute for Manufacturing; 2006.

[5] Holkar CR, Jadhav AJ, Pinjari DV, Mahamuni NM, Pandit AB. A critical review on textile wastewater treatments: possible approaches. Journal of environmental management. 2016;182:351-66 doi: 10.1016/j.jenvman.2016.07.090.

[6] Agency IE. World energy outlook: OECD/IEA Paris; 2009.

[7] Amed I, Berg A, Balchandani A. The state of fashion. 2023.

[8] PROTECTION E. Environmental protection agency (EPA). 2003.

[9] Ozturk HK. Energy usage and cost in textile industry: A case study for Turkey. Energy. 2005; 30(13):2424-46. doi: 10.1016/j.energy.2004.11.014.

[10] Hasanbeigi A, Price L. A review of energy use and energy efficiency technologies for the textile industry. Renewable and Sustainable Energy Reviews. 2012;16(6):3648-65. doi: 10.1016/j.rser.2012.03.029.

[11] Hasanbeigi A, Price L. A technical review of emerging technologies for energy and water efficiency and pollution reduction in the textile industry. Journal of Cleaner Production. 2015;95:30-44. doi: 10.1016/j.jclepro.2015.02.079.

[12] Wallin J. Case studies of four installed wastewater heat recovery systems in Sweden. Case Studies in Thermal Engineering. 2021;26:101108. doi: 10.1016/j.csite.2021.101108.

[13] Łokietek T, Tuchowski W, Leciej-Pirczewska D, Głowacka A. Heat Recovery from a Wastewater Treatment Process—Case Study. Energies. 2022;16(1):44. doi: 10.3390/en16010044.

[14] Campbell N, Ryan L, Rozite V, Lees E, Heffner G. Capturing the multiple benefits of energy efficiency. IEA: Paris, France. 2014.

[15] Worrell E, Laitner JA, Ruth M, Finman H. Productivity benefits of industrial energy efficiency measures. Energy. 2003;28(11):1081-98.

[16] Hayes RH, Abernathy WJ. Managing our way to economic decline. Harvard Bus Rev;(United States). 1980;58(4).

[17] Jorgenson D, Gollop FM, Fraumeni B. Productivity and US economic growth: Elsevier; 2016.

[18] Syverson C. What determines productivity? Journal of Economic literature. 2011;49(2):326-65. doi: 10.1257/jel.49.2.326