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The Role of Renewable Energy in Confronting Climate Change and Reducing the Environmental Impact of the Apparel Industry

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Abstract
In recent times, the world has been striving to transition to a clean, green environment to achieve sustainable development. With climate change posing numerous challenges, it is crucial to swiftly shift to a clean environment for a better future free from environmental pollution. The research problem lies in determining to what extent the use of renewable energy in Apparel factories contributes to environmental preservation and cost reduction. The importance of this research is highlighted by focusing on renewable energy and its benefits, and reducing the environmental pollution caused by conventional energy sources. This research aims to achieve sustainability and climate preservation through the use of renewable energy in Apparel factories, and to reduce electricity consumption costs in these factories. The research hypothesis is as follows: the use of renewable energy preserves the environment and reduces electricity costs in Apparel factories. This research employs a descriptive methodology using analytical techniques to describe and analyze renewable energy and its applicability in Apparel factories. Costs were calculated under three scenarios: electricity-only, On-Grid, and Off-Grid systems. The results indicated that the On-Grid system is the least expensive, Followed by the Off-Grid system. which confirms the validity of the research hypothesis and achieves the research objectives. Recommendations of the study include raising awareness about the importance and benefits of using renewable energy and keeping pace with global efforts to mitigate climate change using renewable energy.

Keywords
Renewable energy, Apparel industry, Sustainable manufacturing, The Environmental Impact Assessment, Climate change

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Introduction

Sustainability is increasingly vital in the global market, with manufacturers facing losses for neglecting it. While developed countries have made progress, developing nations need to focus on sustainable products and new technologies to remain competitive. (Gunjan Yadav, et al., 2020) Reducing the negative impacts of technology on society and the environment is vital. Unlike the traditional "take, make, dispose" model, which depletes resources and harms the environment, sustainable manufacturing (SM) follows a regenerative approach, optimizing resource use throughout its lifecycle. (Rupesh Chourasiya, et al., 2024), Renewable energy offers a promising path forward amid the environmental costs of our current energy system. The shift to renewables is gaining momentum, though it faces challenges like grid balancing, policy changes, and economic viability. Despite these hurdles, renewables show potential for a sustainable, cost-effective energy future with minimal impacts. (David Elliott, 2016), The use of renewable energy is increasing as advancements in technology have made it more affordable and accessible to fulfill the demand for sustainable energy sources. (Sajida Kousar, et al., 2022). fossil fuel burning and GHG emissions are the most impacted barrier. (MT Siraj, et al., 2023) The global fashion industry heavily relies on man-made fibers like polyester, which constitute 72% of textile production, leading to significant environmental impacts. With

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apparel production nearly doubling in the past two decades due to rising consumer demand, global consumption could cause a 50% increase in greenhouse gas emissions if trends continue, according to the Ellen MacArthur Foundation. To address this, the European Union is introducing a carbon tax across various sectors under the EU Green Deal, aiming for carbon neutrality by 2050. (Radi Shafiq, 2024). Innovative technologies like renewable energy, carbon capture, and emissions monitoring can benefit the textile and apparel sector, though high implementation costs are a challenge. This industry is vital for job creation in low and middle-income countries but faces sustainability issues, including short product life cycles and high water consumption. To address these challenges, the industry is shifting towards a circular model to extend product life cycles and improve second-hand clothing recycling. (Weilin Xu, et al., 2024)

Research Problem

Although the use of renewable energy in Apparel industry has many environmental and economic benefits, there is a scarcity of its use in factories. Therefore, the research aims to answer the following questions:

- To what extent does the use of renewable energy in Apparel factories contribute to environmental preservation?
- To what extent does the use of renewable energy help reduce costs in Apparel factories?

Research Significance

The importance of this research is due to:

- Highlighting renewable energy and its benefits.
- Reducing environmental pollution caused by conventional energy sources.

Research Objectives

This research aims to:

- Achieving sustainability and preserving the climate through the use of renewable energy in Apparel factories.
- Reducing electricity consumption costs in Apparel factories.

Research Hypotheses

- The use of renewable energy preserves the environment.
- The use of renewable energy reduces electricity costs in Apparel factories.

Research Methodology

The research followed the descriptive approach, using the analysis method in describing and analyzing The electrical capacity of the factory under study, Analyzing the calculating energy costs in three cases: The traditional method - using solar energy in two ways.

Research Delimitation

The research limits are: The research was limited to the use of solar energy in Apparel factory for the production of men's trousers.

Research Terminology

Renewable energy

It is a rapidly growing field, embraced by many as a key solution to climate change and energy security challenges. (David Elliott, 2020)
Renewable energy is energy derived from natural resources that are replenished or cannot be exhausted, renewing at a rate faster than consumption. It is characterized by its rapid renewal and availability. Its sources vary and include solar energy, wind energy, hydropower, biomass energy, geothermal energy, and others. Sustainable energy = renewable energy + energy efficiency.
(Halassa, Hanaa and Trayeche, Moamer, 2024)

Sustainable Manufacturing (SM)

Sustainable manufacturing (SM) is a crucial process for achieving the Sustainable Development Goals (SDGs). Some companies address SM challenges by adopting sustainable techniques. SM is evolving as a framework for sustainable development, based on the principles of the 6Rs: reduce, reuse, recycle, remanufacture, repair, and renew. Integrating these six principles of sustainability into the product life cycle promotes resource conservation and environmental protection. (Rupesh Chourasiya , et al., 2024)

Sustainable Technology:

Sustainable product innovation involves eco design, ecolabeling, life cycle assessment, materials, and packaging. Process innovation focuses on cleaner production, eco-efficiency, waste management, and enzymatic textile processing. Organizational innovation includes environmental management systems (EMS), corporate policies, collaboration, business model innovation, culture, and knowledge management. (Harsanto, B., Primiana, 2023)

Circular Economy (CE)

The circular economy (CE) focuses on minimizing waste and optimizing resource use through reusability, recycling, and sustainable practices, with companies designing durable, repairable products and investing in renewable energy to reduce emissions. Achieving circularity involves rethinking product design, adopting new business models, and embracing digitalization and supply chain collaboration to enhance environmental performance and competitiveness.

(Rupesh Chourasiya, et al., 2024)

The Environmental Impact Assessment (EIA)

The Environmental Impact Assessment (EIA) is a key tool for planning and ensuring sustainable development, aimed at protecting the environment and natural resources during industrial and infrastructure projects. It functions as both a planning and decision-making tool. (Samantha Sharpe, et al., 2022)

Climate change

Climate change refers to substantial, long-term alterations in the Earth's climate, including shifts in temperature, precipitation, and wind patterns. It is primarily driven by human activities like burning fossil fuels, deforestation, and industrial processes, which elevate greenhouse gas levels in the atmosphere. This leads to global warming and causes various environmental consequences, such as rising sea levels, more frequent extreme weather events, and changes in ecosystems. (IPCC, 2021)

Climate change is portrayed as a critical global challenge that demands swift, practical, and ethical responses to achieve a sustainable future.

The concept of climate change is framed as a critical and evolving issue with several key aspects:

- **Urgency:** Climate change needs prompt and decisive action to address its impacts.
- **Decarbonization:** Eliminating fossil fuels and transitioning to fossil-free alternatives is crucial.
- **Systems Thinking:** Understanding emission sources and focusing on practical, existing solutions is essential.
- **Moral and Scientific** Responsibility: There is a moral and scientific need to act against climate change and abandon fossil fuels.
- **Empowering Action:** More people need to be equipped to drive decarbonization and build practical solutions. (Jonathan Koomey, Ian Monroe, 2022)

PREVIOUS STUDIES

Study (Biswas, Mithun Kumar, et al., 2024), Titled " Navigating Sustainability through Greenhouse Gas Emission Inventory: ESG Practices and Energy Shift in Bangladesh's Textile and Readymade Garment Industries, Environmental Pollution"

This study addresses the gap between the rising global demand for clothing and textiles and the increasing greenhouse gas emissions.by creating a comprehensive GHG emission inventory for 2022, focusing on Bangladesh's textile and readymade garments (RMG) industries. It evaluates emissions from fuel combustion, electricity use, and waste treatment, with textiles contributing 67.8% and RMG 32.2% of the total 6043.5 Gg CO2eq. The study also forecasts emissions until 2030 and explores the effects of different energy scenarios, aiming to drive sustainable transitions in Bangladesh and other developing nations.

Study (Kaniz Farhana, et al., 2022), Titled "Energy consumption, environmental impact, and implementation of renewable energy resources in global textile industries: an overview towards circularity and sustainability"

This study examines the energy consumption, environmental impact, and adoption of renewable energy in the textile and Apparel industry to promote circularity and sustainability. While textiles are essential, the sector relies heavily on fossil fuels, leading to significant environmental harm. Transitioning to renewable energy is crucial for reducing this impact. The study reviews fossil fuel usage, explores cleaner alternatives, and suggests that implementing Best Available Techniques (BAT) and advanced technologies can improve energy efficiency. Shifting to renewable energy in textile production is vital for protecting the environment and ensuring sustainable practices.

Study (Sajida Kousar, et al., 2022), Titled "Sustainable Energy Consumption Model for Textile Industry Using Fully Intuitionistic Fuzzy Optimization Approach "

This study examines the optimal use of sustainable energy in Pakistan's textile manufacturing industry, considering the existing environmental and economic conditions. Given the regional potential for renewable energy, solar energy generators are considered, and a fully intuitionistic fuzzy (FIF) textile energy model is developed. Using the FIF model to determine the optimal allocation of solar energy units resulted in a manageable number of unused energy units. These surplus units can be returned to the central power supply station, saving both energy and costs, The installation of this solar plant led to both cost savings and a reduction in the carbon footprint.

Study (Greg Peters, et al., 2021), Titled "The need to decelerate fast fashion in a hot climate - A global sustainability perspective on the garment industry "

This article evaluates the impacts of fast fashion using the Eora multiregional model, focusing on environmental and social indicators such as energy consumption, climate effects, water use, wages, and employment. It finds that while the climate impact of clothing and footwear rose slightly from 1.0 to 1.3 Gt CO2 equivalent from 2000 to 2015, key countries like China, India, the USA, and Brazil are major contributors. Despite a 75% increase in textile production, per-garment impacts have improved due to greater efficiency. However, climate and water use impacts remain significant compared to social benefits like employment. To further reduce the fashion industry's carbon footprint, a shift away from fossil fuels and the fast fashion model is necessary.

Theoretical Framework

We are at a pivotal moment for humanity and the planet. Our mission is to shift from a world of climate instability and environmental decline to one that halts global warming, achieves net zero, and promotes a climate-positive future for both people and nature. We urgently need more individuals with the urgency, knowledge, and skills to help bridge this transition. (Jonathan Koomey ,Ian Monroe, 2022)

Manufacturers are shifting to green energy due to new regulations and growing customer climate awareness. Addressing reliance on fossil fuels and grid instability is key for decarbonization. Significant changes in the energy ecosystem are needed, especially for industries that depend on a steady electricity supply, like textile mills. (Radi Shafiq, 2024)

Sustainable Product Design and Development

Sustainable product design and development are essential for creating a more eco-friendly and sustainable fashion industry. Reducing the environmental impact of textile and apparel products can be achieved through methods such as closing the manufacturing loop, applying eco-design principles, conducting life cycle analysis, and implementing product certification and labeling. (Roy, R., Chavan, et al., 2024)

The following figure (1) illustrates the Sustainable Development Goals and their branches. (Apurbo Sarkar, et al., 2020)

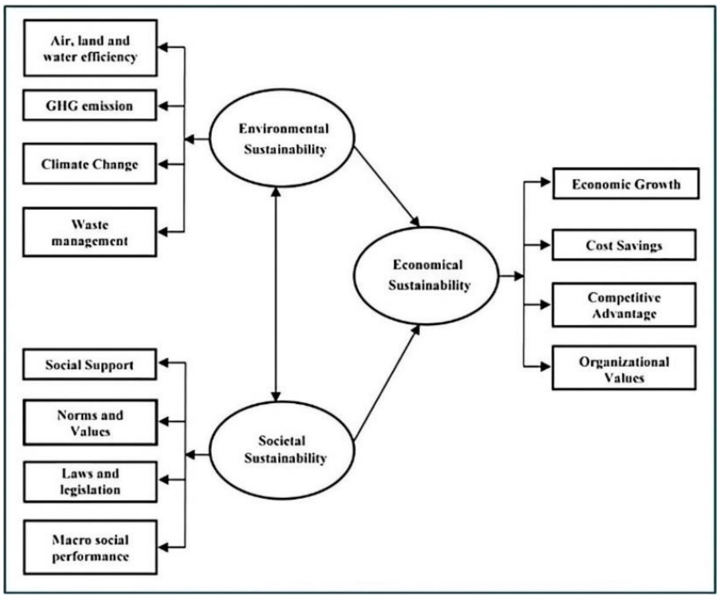

Figure (1) The Objectives of Sustainable Development

To achieve environmental goals, companies must measure green initiatives and identify areas for improvement. Sustainable Management (SM) focuses on reducing waste, conserving resources, and protecting the environment by analyzing supply chain operations for efficiency and impact. Some of the most important performance measurement indicators**:**

Environmental Perspective:

The environmental perspective emphasizes sustainable practices like reducing emissions, energy, and water use, while adopting renewable energy, waste reduction, and eco-friendly production methods. Key aspects include:

- Energy Efficiency: Analyzing energy use to find opportunities to reduce environmental impact and operational costs.
- Greenhouse Gas Emissions: Tracking emissions to set reduction targets and combat climate change.
- Water Usage: Monitoring water use to identify conservation opportunities and minimize ecological impact.
- Waste Generation: Reducing waste through recycling and adopting circular economy practices.
- Material Efficiency: Conserving resources by optimizing material use, recycling, and reusing materials.

Economic Perspective:

- The economic perspective focuses on the production, distribution, and consumption of goods and services using economic principles. Key performance indicators include:
- Cost of Production: Comparing costs of sustainable vs. traditional practices to assess economic viability.
- Return on Investment (ROI): Measuring financial returns from sustainable initiatives to justify investments.
- Market Share and Reputation: Assessing how sustainability impacts consumer preferences, loyalty, and competitive advantage.
- Revenue from Services: Offering upgrade, repair, and maintenance services to enhance sustainability and long-term success.
- Product Life Cycle Assessment (LCA): Analyzing environmental impacts across a product's entire life cycle, from raw material extraction to disposal or recycling.

Supply Chain (SC) Perspective:

The supply chain perspective is essential for evaluating sustainable management by addressing environmental and social impacts across the entire supply chain. Key aspects include:

Supply Chain Transparency: Disclosing sourcing methods and sustainability standards to ensure accountability and ethical practices.

-Supplier Sustainability Performance: Aligning supplier practices with the organization's sustainability goals.
-Carbon Footprint Reduction: Reducing emissions from transportation, manufacturing, and energy use.
-Resilience and Risk Management: Managing sustainability risks like climate change and resource scarcity for a resilient supply chain. (Rupesh Chourasiya , et al., 2024)
Sustainable technology as defined by the United Nations Environmental Program (UNEP), falls into four categories: reducing carbon dioxide and other greenhouse gas emissions, substituting materials or fuels, enhancing material or energy efficiency, and recycling technologies. Clean technology aims to cut pollution and resource use, while energy-saving technology focuses on improving efficiency. Environmental technology seeks to lower energy and material consumption while minimizing environmental harm. (Hoque, M.A., et al., 2023)

Sustainable Production Processes in Apparel Industry:

Energy-Efficient Manufacturing Processes.
Reduced Environmental Impact.
Closed-Loop Production Systems.
Chemical Management and Substitution.
Energy-Efficient Manufacturing Processes.
use Renewable Energy.
Process Improvement.
Water Conservation Practices.
Water Recycling.
Waste Reduction and Recycling. (Roy, R., Chavan, et al., 2024)
Sustainable manufacturing is increasingly important worldwide as industries shift from traditional, resource-heavy methods to greener practices. However, many face challenges in adopting these sustainable processes, struggling to overcome barriers and fully implement eco-friendly manufacturing. (AK Bambam, KK Gajrani, 2023)
Companies are increasingly adopting green energy, such as solar panels and energy-efficient systems. Bangladesh has notable LEED-certified factories like AR Jeans Producers, which uses a 45 kW solar plant and energy-saving features, and Plummy Fashions, which sources 13% of its energy from solar panels and saves 50% more energy. (Radi Shafiq, 2024)
A recent NREL study predicts that wind and solar power could supply 60%-80% of electricity by 2035, with the Department of Energy's SolWEB program funding $14 million for research on ground-mounted solar systems' environmental impacts. Addressing climate change also involves protecting biodiversity, necessitating careful planning and investment in technology to balance decarbonization and wildlife conservation. (Alejandro Moreno, 2022)
Renewable energy sources, though abundant, are variable and require compensation methods for stability, with fossil fuel plants serving as backups. As renewables supply 23% of global electricity, renewables could rise to 50% or more by mid-century, potentially supplying 80-90% of electricity and meeting most heating and transportation needs in many countries. (David Elliott, 2016)
For a sustainable economic future with renewable energy, policymakers must address fossil fuel industry interference, as allowing both to operate during a climate emergency can stifle innovation. To promote sustainable growth, it is essential to stop supporting fossil fuels and discourage anti-competitive behavior. (Deborah E. de Lange, 2024)

The Importance of Renewable Energy

The importance of renewable energy lies in its role as an alternative to traditional energy sources. It is characterized by being clean and environmentally friendly, ensuring continuous availability and reliability, The following figure (2) illustrates this. (Barakat, Ahmed, and Nasif, Hassan. 2020)

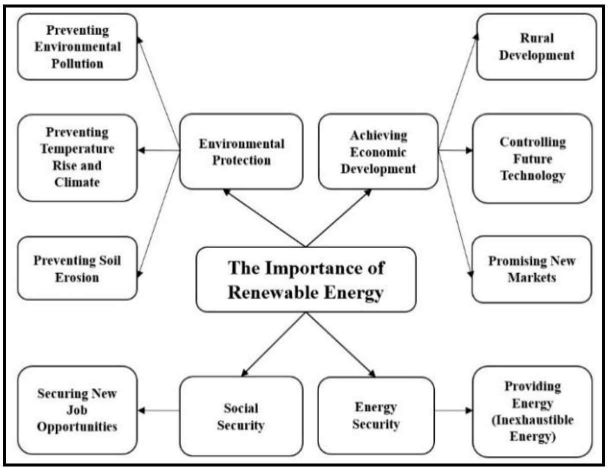

Figure (2) The Importance of Renewable Energy

Local governments can significantly lower their carbon footprint by using or generating electricity from clean, renewable sources. Common renewable energy technologies.

Types of renewable energy:

- Solar (photovoltaic, solar thermal)
- Wind, Biogas (landfill gas/wastewater treatment digester gas)
- Geothermal, Biomass, Low impact hydroelectricity
- Emerging technologies wave and tidal power.
- (www.epa.gov/statelocalenergy/local-renewable-energy-benefits)

Future Capacity of Solar Energy

Solar energy offers more flexibility than wind and hydropower due to its consistent and predictable nature. By storing daytime energy for nighttime use and increasing DC to AC ratios, advanced solar plants will provide more reliable service. Encouraging wider adoption of solar energy requires government incentives, effective regulations, and remuneration schemes.

Solar's role in renewable energy growth is significant, with the IEA attributing 60% of the sector's growth to solar due to its accessibility and decreasing costs. Carbon Tracker also predicts that by 2040, 72% of coal power will be unprofitable globally. (Emily Folkglobal, 2021)

The Future Lies in Renewable Energy

In the coming decade, renewable energy is set to gain ground over fossil fuels, leading to a reduction in greenhouse gas emissions.

"Solar and wind technologies are central to the ongoing transformation of the global energy system. Their expanded use is essential for addressing greenhouse gas emissions, reducing air pollution, and improving energy access."

Benefits of Switching to Renewable Energy:

1- **Cost-Effective:** Renewable energy costs have dropped significantly, with many options cheaper than coal. Returns on investment are often seen within five years.
2- **Environmental Advantages:** Reducing fossil fuel use helps lower GHG emissions and combat global warming, offering a sustainable alternative for industries like textiles.
3- **Customer Engagement:** Consumers favor brands that prioritize sustainability. Using renewable energy aligns with customer values and showcases a commitment to the environment.
4- **Competitive Edge:** Reliable renewable energy sources can help companies avoid production delays and reduce costs, providing a competitive advantage.
5- **Energy Efficiency Monitoring**: Transitioning to renewables enables better tracking of energy use, helping companies optimize processes and update inefficient machinery. (Scarlett Buckley, 2022)

Renewable energy is abundant and sustainable, meeting current needs while preserving resources for the future. It supports sustainable industrialization, efficient resource use, and technological progress, contributing to Sustainable Development Goals SDG 9 (Industry, Innovation, and Infrastructure). By enhancing energy conservation and efficiency, renewable energy addresses both economic and environmental sustainability. Green textile

plants using renewable energy reduce carbon emissions, waste, and resource consumption, aligning with SDG 13 (Climate Action). These practices help mitigate climate change, pollution, and biodiversity loss, promoting overall sustainability.
(Saifur Rahman Tushar, et al., 2024)

The government recognizes the importance of renewable energy, and Waste-to-Energy (WtE) technologies offer a sustainable electricity source while reducing landfill waste. WtE efficiently converts municipal solid waste into electricity and heating, aligning with global efforts like the Paris Agreement and SDGs. As global energy demand rises, WtE presents a solution to challenges in waste management, energy security, and fossil fuel dependency, especially in emerging economies. It can help reduce greenhouse gas emissions, decrease landfill waste, and contribute to achieving sustainable development goals. (Md. Ruhul Ferdoush, et al., 2024)

Rising electricity costs impact profit margins, and with only 4.5% of energy from renewables, the country risks falling behind under new EU carbon regulations. Investing in renewable energy is crucial to address fossil fuel dependence and grid instability, aiding decarbonization and maintaining global competitiveness. (Radi Shafiq, 2024)

Solar energy is vital for reducing greenhouse gas emissions and mitigating climate change, helping protect humans, wildlife, and ecosystems. It also enhances air quality, conserves water, and provides benefits like carbon sequestration and stormwater management for local communities.
(https://www.energy.gov/eere/solar/solar-energy-wildlife-and-environment)

The key difference between renewable and non-renewable energy is that renewable energy is limitless, while non-renewable energy depletes with use. Additionally, non-renewable energy is much more damaging to the environment and a leading cause of climate change. Non-renewable energy sources release harmful greenhouse gases, contributing to the greenhouse effect and global warming. They also cause pollution and lead to habitat destruction.
(www.energy.gov/eere/environmental-impacts-clean-energy)

Currently, renewable energy consumption primarily relies on the grid, but large-scale integration poses several challenges:

1- Increased System Costs: Grid connection increases safety, balancing, grid expansion, and access costs, especially when renewable penetration exceeds 15%, causing rapid cost growth.
2- Grid Operation Issues:
   - Random Volatility: Weather-dependent energy sources like wind and solar can cause power fluctuations, affecting grid stability.
   - Harmonics: Renewable energy can generate harmonic resonance through transmission lines, causing overvoltage and safety risks.
3- Grid Management: Increased renewable energy integration complicates power system management, affecting supply quality and safety. (Yuan-ying Chi, et al., 2024)

The textile industry, while a key player in the global economy, is also a major polluter. With growing awareness of climate change, the sector is turning to renewable energy sources like solar, wind, and hydropower. Solar energy, in particular, is ideal for powering production equipment, leading many textile companies to install rooftop solar panels to reduce reliance on traditional energy sources.

Ready-made garment (RMG) companies are under significant pressure to enhance their competitiveness while taking decisive action to reduce pollution and minimize their ecological footprint. (Apurbo Sarkar, L Qian and AK Peau. 2020)

Adopting sustainable production practices is vital for rapidly industrializing emerging economies to avoid losing global market share and damaging ecological balance. In 2018, the fashion industry emitted about 2.1 billion metric tons of greenhouse gases. AMI, a major industrial player in Bangladesh, heavily relies on fossil fuels. There are significant climatic impacts from apparel consumption in China, India, the U.S., and Brazil. (Binoy Debnath, et al., 2024)

H&M is making its supply chain more eco-friendly by minimizing cotton production impacts and using sustainable materials. The company has also improved its supply chain and launched a recycling program, offering discounts to customers who recycle their old clothes. (Roy, R., Chavan, et al., 2024)

With the goals of "carbon peak" and "carbon neutrality" established, the shift towards a low-carbon energy structure, primarily moving away from coal and coal power, alongside the advancement and adoption of technologies such as renewable energy, carbon utilization, capture, and storage, presents both opportunities and challenges for high-quality development. (Yingjie Feng , et al., 2024)

Textile and apparel manufacturing consumes significant energy, water, and resources, leading to high waste generation. In response, the industry has increasingly adopted sustainable practices to address the climate crisis and environmental impact. The rise of fast fashion and growing consumer demand have significantly boosted apparel production, generating substantial waste across all stages, including spinning, weaving, dyeing, and apparel production. (Md Shams uzzaman, et al., 2021)

The Apparel industry is a large sector that encompasses the design, production, marketing, and distribution of clothing and accessories. The apparel industry takes priority as it remains heavily reliant on manual labor, particularly in tasks like marker laying, fabric cutting, sewing, and finishing. While still require manual work. Some leading factories from other textile sectors have also been included for comparison. (Israt Zahan Mim, et al., 2024)

Sustainable Apparel manufacturing focuses on cleaner production methods to reduce environmental impact. Key initiatives include water recycling, renewable energy use, and eco-friendly materials, all aimed at enhancing energy efficiency, conserving resources, and minimizing pollution. In the apparel sector, sustainable efforts have grown, incorporating eco-friendly supply chain management, cost-effective production, and socially responsible practices. The industry is adopting long-term strategies like life cycle assessments, efficient distribution, and circular practices such as recycling, reuse, and material disassembly. Green manufacturing is increasingly important, supporting the social, economic, and ecological "triple bottom line." Apparel production, which traditionally relies on fossil fuels, is shifting towards renewable energy sources like biomass, solar, and LPG, with successful examples like a Greek textile company using biomass to meet 52% of its thermal needs. Despite initial challenges, adopting these cleaner practices can significantly reduce the environmental footprint while maintaining product quality and market competitiveness. (Md. Tareque Rahaman, et al., 2024)

To reduce GHG emissions in the EU-27 textile and clothing industry, improving energy efficiency and decreasing reliance on polluting energy sources is essential. Transitioning to renewable energy and implementing energy efficiency policies are crucial for achieving a carbon-neutral industry. (Rocío Román-Collado, et al., 2023)

As global population and economic growth increase energy demand, fossil fuels are becoming more costly and harmful, driving pollution and climate change. In 2020, fossil fuels made up 61.3% of global electricity, highlighting their major role in emissions. With depletion and environmental damage rising, the shift to sustainable energy is urgent. Decarbonizing energy systems is challenging, but renewable energy could cut the electricity sector's carbon footprint by 90% by 2050. Boosting energy efficiency and renewable energy use is key to mitigating climate change and enhancing carbon productivity. (Binoy Debnath, et al., 2023)

To combat climate change, we must aim for net zero emissions by 2040 and become climate positive to reverse damage. Fossil fuels and land-use changes drive CO_2 emissions, which stay in the atmosphere for centuries, intensifying warming. The technology to reach net zero exists, but the real hurdles are social, political, and economic. Immediate action is crucial—global emissions need to be halved by 2030 to limit warming to 1.5°C. Industrialized nations should accelerate the adoption of zero-emission technologies, as the benefits of climate action far outweigh the costs. (Jonathan Koomey and Ian Monroe. 2022)

Climate change is a major global crisis, making the sustainable use of resources crucial. Sustainability encompasses human, social, economic, and environmental aspects. Sustainable manufacturing aims to minimize environmental impact while conserving resources. This chapter explores ecological cooling/lubrication methods in manufacturing, highlighting research that reduces or replaces petroleum-based fluids in metal cutting. Emerging trends include minimum quantity lubrication (MQL), nanoparticle-doped nanofluids, hybrid nanofluids, cryogenic cooling, and hybrid cooling/lubrication techniques. (Şenol Şirin. 2023)

To stabilize the climate, five key technical strategies are essential: electrifying nearly all sectors, decarbonizing the electricity grid, reducing non-fossil fuel emissions, enhancing efficiency and optimization, and removing carbon from the atmosphere.
(Jonathan Koomey and Ian Monroe . 2022)

There must be an action plan to address climate change, which is the rapid transition to renewable energy. Undoubtedly, the human causes of climate change are well-known to many and extensively documented by the scientific community: excessive burning of fossil fuels, rapid deforestation, large-scale industrial food production, high levels of consumption, among others. (Tokay, E, 2023)

To reduce GHG emissions in fast fashion, energy efficiency and renewable energy adoption in upstream operations are essential. As climate concerns intensify, the fast fashion industry must address its substantial contribution to global emissions and waste, which accounts for nearly half of the fashion sector's impact, Technological innovations, like shifting from wet to dry processing, can help. As the industry faces increasing climate pressures, companies must invest in decarbonization, recycling, and sustainable materials to minimize their environmental impact and move towards a more sustainable future. (Brianna Wren, 2022)

The Fashion industry leaves its mark on the environment throughout its supply chain, but the impact isn't evenly distributed. Four key areas are responsible for a concentrated amount of environmental damage:

1- **Textile Production:** Weaving, dyeing, and finishing processes are particularly harmful due to their high water consumption, reliance on toxic chemicals, and often inadequate wastewater treatment.
2- **Energy Usage:** Throughout the entire supply chain, significant energy is used, often from sources with high carbon emissions.
3- **Textile Waste:** Apparel assembly generates a substantial amount of textile waste, adding to the environmental burden.
4- **Global Transportation:** Shipping raw materials and finished products across the globe adds to the industry's carbon footprint.

Textile production and energy use are the largest contributors to environmental degradation, majorly responsible for toxic chemical emissions and poor wastewater treatment. This is primarily due to excessive water consumption and reliance on high-carbon energy sources. (Samantha Sharpe, et al., 2022)

The apparel manufacturing sector is a significant contributor to water pollution, discharging untreated wastewater into rivers and accounting for 20% of global industrial water pollution and 6–8% of carbon emissions, equating to 1.7 billion tons of $CO2$ in 2015. This carbon footprint is heightened by reliance on coal and natural gas, especially in major producers like China and India. Transitioning to renewable energy sources, such as solar, hydro, or wind power, could substantially reduce emissions and enhance sustainability. The fast fashion trend, marked by high production volumes and low-quality apparel, has further worsened the sector's climate impact, which rose by 35% from 2005 to 2016. Utilizing renewable energy for both electricity and thermal needs is essential for minimizing the environmental footprint of the apparel industry. (Sajida Kousar, et al., 2022)

Successful models in achieving sustainability in Apparel factories. H&M aims to achieve climate positivity across its entire value chain by 2040, while Levi's has committed to becoming net zero by 2050. Other brands such as Primark and Zara have also set similar goals. (Radi Shafiq, 2024)

Experimental work

There is an important question: what is the driving force behind the shift towards renewable or alternative energy? Recently, the world has been actively seeking clean and green energy sources, focusing on how to preserve the environment and raise awareness about the impacts of both climate change and carbon emissions from factories. The use of renewable energy helps eliminate carbon, which is a key contributor to climate change, and also helps reduce costs, especially after the rise in electricity prices.

As mentioned in the theoretical framework, renewable energy has numerous environmental Advantages, such as reducing carbon emissions Which causes global warming, reducing water and air pollution and minimizing waste, and economic advantages, such as lowering energy costs (electricity and water), and creating new job opportunities, and other advantages.

Solar power is vital because it generates energy without harming the planet. As long as the sun continues to shine, we will never need to worry about depleting solar energy. Although the initial costs may be somewhat high, solar panels offer significant advantages. They can be installed on almost any sun-facing surface, making them an ideal solution for powering homes, commercial buildings, or even contributing directly to the power grid.

Sustainable energy sources are far more cost-effective, as they eventually pay for themselves both financially and environmentally. This leads to lower electricity costs for consumers in the long run, Solar energy is harnessed from the sun's rays through silicon solar panels, using the "photovoltaic effect." This process allows solar panels to capture the sun's energy and convert it into electricity.

To implement a renewable energy system in Apparel Industry, the following steps must be taken:

- Encourage the government to promote the use of renewable energy and facilitate the procedures.
- Identify the requirements for obtaining the necessary permits.
- Determine funding sources.
- Understand the benefits of green renewable energy.
- Identify the costs of the renewable energy to be used.
- Assess the costs of various modern technologies that can be implemented.

The following is an analysis of the strengths, weaknesses, opportunities, and threats (SWOT) of using renewable energy in Apparel factories.

Strengths:

- Renewable energy is clean, abundant, and inexhaustible.
- Diversification of energy supplies and reduction of reliance on fossil fuels, which are harmful to the environment.
- Mitigation of climate change.
- Achieving sustainability in its three aspects: environmental, economic, and social.
- Reducing the carbon footprint, as it does not produce greenhouse gas emissions.
- Decreasing air pollution.
- Lowering energy costs.
- Achieving long-term profitability.

Weaknesses:

- High initial costs.
- The need for energy storage to account for any potential climate changes.
- Adequate space must be provided to cover the required energy supply.
- Lack of awareness about the importance of using renewable energy.
- Lack of funding.

Opportunities:

- Expansion in production by entering new markets.
- Government support in facilitating the transition to a clean environment.
- Increased technological innovation, which improves efficiency and reduces costs.

Threats (Challenges):

- Upgrading the current infrastructure to enable optimal use of renewable energies.
- The cost of new technologies and their maintenance.
- Laws, regulations, and required licenses.

A case study was conducted for Apparel factory producing men's trousers, analyzing The electrical capacity of the factory under study, Solar energy was selected from renewable energy sources because the Arab Republic of Egypt benefits from abundant solar resources. Unlike wind energy, it does not require relocating factory workers to the desert, as solar energy is readily available and accessible everywhere. To implement this, the factory's rooftop area was calculated for the installation of solar panels, and it was found to be sufficient to cover the required electrical capacity. The following was done Analyzing the calculating energy costs in three cases: The traditional method - using solar energy in two ways (On Grid, Off Grid).

On-grid refers to the installation of solar panels while still using the local electricity grid, which reduces electricity costs to a quarter of what was previously paid. This means the factory owner will bear the cost of the solar panels in addition to paying a quarter of the amount that was previously spent on electricity.

Off-grid refers to the installation of solar panels only, and these panels require batteries to store solar energy for use at night or during times when sunlight is not available.

The energy costs were calculated for three scenarios: the traditional case (electricity only), the on-grid system, and the off-grid system. To determine the required energy supply, the electrical capacity of the factory was calculated, taking into account all electricity usage, including machines, devices, lighting, and ventilation. The following figures and tables show these calculations.

The following table (1) illustrates the cost details for the electricity-only system, including the required electrical capacity, daily working hours, the number of working days per year, the current electricity price, and the total cost after 5 years and 30 years. It should be noted that the cost of solar panels will be paid once every 30 years.

RESULTS & DISCUSSION

Table (1)Energy consumption costs in electricity only

Energy consumption costs in the case of using electricity only	
Required electric power per hour	56.89 kw
Daily working hours	8.5 H
Required electric power per day	483.565 kw
Required electric power per year (296 days)	143135.24 kw
Electricity consumption cost per kilowatt	2.3 L. E
Total annual cost	329211.05 L. E
Total cost over 5 years (assuming stable prices)	1646055.26 L. E
Total cost over 30 years (assuming stable prices)	9876331.56 L. E

The following table (2) illustrates the cost details for the on-grid system, including the required electrical capacity, daily working hours, the number of working days per year, the current electricity price, the cost of solar panels, and the total cost after 5 years and 30 years (the cost of the panels and the cost of the portion taken from the electrical grid, which is a quarter of what was used in the old system).

Table (2) Energy consumption costs in On Grid

Energy consumption costs in the case of using electricity with solar panels (On Grid)	
Required electric power per hour	56.89 kw
Daily working hours	8.5 H
Required electric power per day	483.565 kw
Required electric power per year (296 days)	143135.24 kw
Electricity consumption cost per kilowatt	2.3 L. E
Quarter of the annual electricity consumption costs	82302.763 L. E
Cost of solar panels per kilowatt	22000 L. E
Total cost of solar panels (30 years)	1251580 L. E
Electricity consumption cost over 5 years	411513.82 L. E
Total cost of electricity and solar panels over 5 years (assuming stable prices)	1663093.82 L. E
Electricity consumption cost over 30 years	2469082.89 L. E
Total cost of electricity with solar panels over 30 years (assuming stable prices)	3720662.89 L. E

The following table (3) illustrates the cost details for the off-grid system, including the required electrical capacity, daily working hours, the number of working days per year, the current electricity price, the cost of solar panels, and the cost of batteries that store solar energy for use at night or during periods without sunlight. It also includes the total cost after 5 years and 30 years.

Table (3) Energy consumption costs in Off Grid

Energy consumption costs using solar panels only (Off Grid)	
Required electric power per hour	56.89 kw
Daily working hours	8.5 H
Required electric power per day	483.565 kw
Required electric power per year (296 days)	143135.24 kw
Cost of solar panels and cables per kilowatt	40000 L. E
Total cost of solar panels (30 years)	2275600 L. E
Total battery costs over 5 years	568900 L. E
Total cost of solar panels and batteries over 5 years	2844500 L. E
Total battery costs over 30 years (6 replacements)	3413400 L. E
Total cost of solar panels and batteries over 30 years (assuming stable prices)	5689000 L. E

According to the results shown in Table No. (4), We find that the cost after 5 years the cost of the proposed on-grid system equals the cost of the traditional electricity system after five years, assuming the electricity price remains stable. This is based on the official rates announced by the Egyptian Ministry of Electricity for factories. Since electricity prices are regularly increased, the initial cost of the solar panels will be recovered after five years or less. After that, the factory owner will only pay a quarter of the electricity cost compared to before, in addition to contributing to environmental protection by reducing pollution. As for the off-grid system, the initial cost will be recovered after approximately 15.5 years.

Table (4) Total energy consumption costs over 5 years

Energy system used	Cost in millions after 5 years
Electricity only	1.65 million L.E
On Grid	1.66 million L.E
Off Grid	2.84 million L.E

The following figure (3) illustrates the cost difference between the three systems after 5 years.

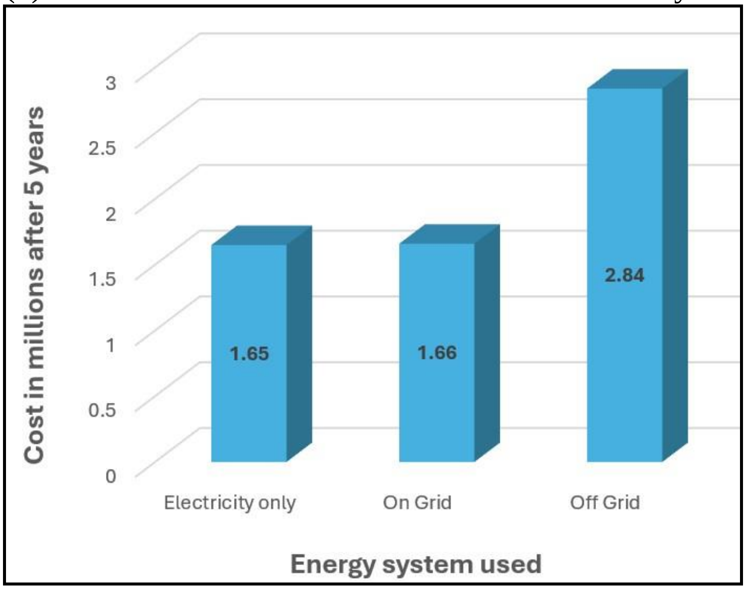

Figure (3) the cost difference between the three systems after 5 years

The Regression Equation and the correlation coefficient were calculated as follows.

Regression Equation: We use the simple linear regression equation

$y = ax + b$, where: x is the type of system, y is the cost.

Correlation Coefficient: We use Pearson's correlation coefficient to determine the strength of the relationship between the system type and the cost.

The Regression line equation

$y = 0.59x + 0.86$

This equation indicates that there is an increase in cost of 0.59 million with each advancement in the energy system type (from "Electricity only" to "On Grid," and then to "Off Grid").

Correlation Coefficient

The correlation coefficient r = 0.87, suggests a strong and positive relationship between the type of energy system used and the cost.

The "Off Grid" system has a significantly higher cost compared to the other systems, and the graph shows that the relationship between system type and cost is strong and positive.

The following figure (4) illustrates The Regression line after 5 years

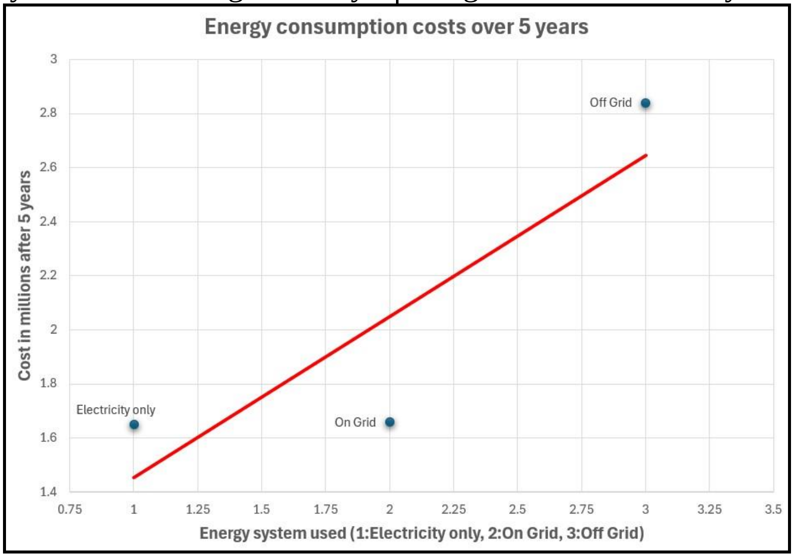

Figure (4) The Regression line after 5 years

According to the results shown in Table No. (5), We find that the cost after 30 years the cost of the proposed on-grid system is lower than both the current electricity-only system and the off-grid system. This means that the on-grid system is the most cost-effective overall, followed by the off-grid system, which relies solely on solar panels. The traditional electricity system comes last with a significant cost difference, in addition to causing environmental pollution and being much more expensive.

Table (5) Total energy consumption costs over 30 years

Energy system used	Cost in millions after 30 years
Electricity only	9.88 million L.E
On Grid	3.72 million L.E
Off Grid	5.69 million L.E

The following figure (5) illustrates the cost difference between the three systems after 30years.

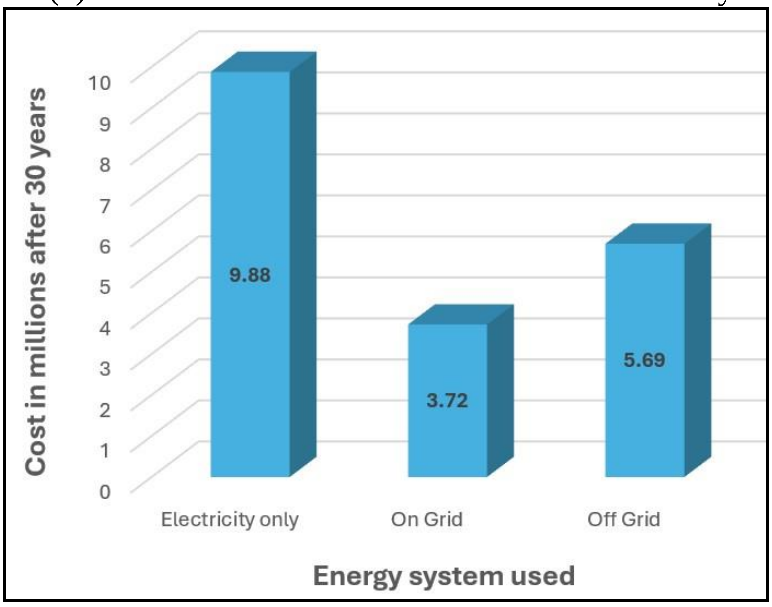

Figure (5) the cost difference between the three systems after 30 years

The Regression line equation:
y = −2.10x + 10.62
Correlation Coefficient:
The correlation coefficient is r = −0.67, indicating a moderate negative relationship between the type of system used and the cost. As we move from higher-cost systems like "Electricity only" to more economical systems like "On Grid," the cost decreases.
The following figure (6) illustrates The Regression line after 30 years.

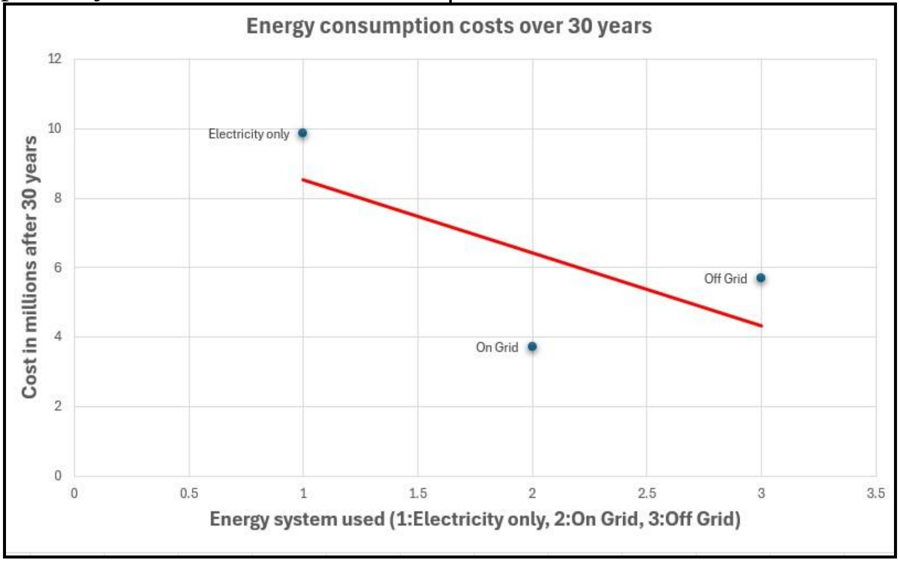

Figure (6) The Regression line after 30 years

From the previous results, we conclude that the most environmentally friendly system is the Off-Grid system, as it relies 100% on solar energy, followed by the On-Grid system, which depends 75% on solar energy.

Recommendations of the research

- Raise awareness about the importance and benefits of using renewable energy.
- Keep pace with global efforts to mitigate climate change by using renewable energy.
- Assess the environmental impact of projects.
- Encourage governments to support existing renewable energy projects.
- Support innovation in new technologies.

Conclusion

To build a brighter future, we must embrace clean energy for sustainability. By prioritizing environmental well-being and economic prosperity, clean energy can unlock a secure and prosperous future. Committing to sources will create jobs and drive growth, making the phase-out of coal essential for a healthier planet and economy. The time to act is now let's adopt green energy solutions for a thriving future, Global warming is a global crisis, and rising energy consumption is a growing concern. Renewable energy, particularly solar power, is being explored as a solution for conserving resources. Adopting renewable energy sources like solar, wind, and hydropower in the Apparel industry is a significant move towards sustainability. As more companies embrace these technologies, we can anticipate lower carbon emissions and a greener, more eco-friendly industry. The importance of this research is highlighted by focusing on renewable energy and its benefits, and reducing the environmental pollution caused by conventional energy sources. This research aims to achieve sustainability and climate preservation through the use of renewable energy in Apparel factories, and to reduce electricity consumption costs in these factories. The research hypothesis is as follows: the use of renewable energy preserves the environment and reduces electricity costs in Apparel factories. This research employs a descriptive methodology using analytical techniques to describe and analyze renewable energy and its applicability in Apparel factories. Costs were calculated under three scenarios: electricity-only, On-Grid, and Off-Grid systems. The results indicated that the On-Grid system is the least expensive after 5 and 30 years, Followed by the Off-Grid system, Knowing that the Off-Grid system is the most environmentally friendly because it uses solar energy only. which confirms the validity of the research hypothesis and achieves the research objectives. Recommendations of the study include raising awareness about the importance and benefits of using renewable energy and keeping pace with global efforts to mitigate climate change using renewable energy.

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