Research Article

Sustainable Energy Consumption Model for Textile Industry Using Fully Intuitionistic Fuzzy Optimization Approach

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Consumption of renewable energy is on the rise because new technologies have made it cheaper and easier to meet the needs of a long-term energy source. In the present study, the idea of optimal usage of sustainable energy is discussed, taking into consideration the environmental and economic conditions that exist in Pakistan’s textile manufacturing industry. By taking into account the regional potential for the application of renewable energy resources, solar energy generators are taken into consideration, and a fully intuitionistic fuzzy (FIF) textile energy model is constructed. Using the FIF model to determine the optimal distribution of solar energy units resulted in a tolerable number of unused energy units. These units may be returned to the central power supply station, which would save both money and energy.

1. Introduction

In the textile industry, electricity and thermal energy usage is the most common, as generated at industrial level through nonrenewable energy resources (petroleum, hydrocarbon gas liquids, natural gas, coal, etc.) or obtained directly through the government according to industrial policies. For example, in Pakistan, coal, nuclear, natural gas, hydroelectric, wind, and solar generators are the major electricity developing sources. Specifically, in Pakistan, the two crucial electricity producers are WAPDA (water and power development authority) that generates hydroelectricity and PEPCO (Pakistan electric power company) where distribution companies (DISCOs) under PEPCO work to maintain the path between electricity producers to consumer end by purchasing and selling it to representative area distribution companies. Except for one (K-electric), all these companies are owned by the government, and hence, the government provides different policies to different consuming sectors. In Pakistan, the energy crisis has been a never-ending situation from last two decades due to imbalance production and consumption ratio. At this point of energy crisis, the government of Pakistan and APTMA (All Pakistan Textile Mills Association) are on continuous conflict regarding the availability and favourable rates of energy. Working of textile industry is based on multiple stages like spinning, weaving, rewinding, dying, and so on, which are further subdivided into several other stages (see Figure 1).

All those stages require a huge amount of energy for their processing. Proper energy management planning can help industries to survive in natural crises or any other unpredictable conditions. Only if a single factor like energy optimization is focused, firstly, it will help industries to minimize their investing cost; secondly, the buyer will be able to get the product at a low cost. Thirdly, the saved energy will be used by other sectors like domestic sectors to
fulfill their energy need and most importantly for the sake of healthy environmental and economic conditions, energy saving is a significant step. In the present time, when COVID-19 or other natural and economic disasters are happening, it is almost impossible to make an accurate and successful management plan. To ensure better energy management for textile industries under all these circumstances, developing an energy optimization model that can work in uncertain situations and generate the best optimal output is needed. To reduce the energy cost, one way is to reconsider the source of energy and replace it with the best convenient sustainable resource. Another way is to allocate energy units optimally. For the first way, considering the situation of Pakistan, it is best for textile industries to generate their own electricity and thermal energy through the Solar System. For the second way, it is best to modify the linear programming (LP) model for the textile industry according to the fuzzy environment. For this purpose, the conversion of the objective function, constraint equations, demand, and supply into fuzzy number is needed. Precisely that fuzzy number can overcome the uncertainty regarding material availability, working hours, financial and social barriers, labour, money, and space.

2. Literature Review

Although in Pakistan, textile industries cover 46% of the whole manufacturing sector and are a macro contributor with 8.5% of Pakistan’s gross domestic product (GDP), it is also a huge environmental pollution contributor. In this setting, textile industries have a significant share in water and air pollution. The amount of clean water utilized by the textile industrial sector is substantially more as compared to the agricultural one [1], and for the production of one kg fabric output at the wet processing stage, the amount of water needed is almost 80–150 liters in addition to other chemicals [2]. Not only that, the report of 2015 stated that textile sector solely accounted for 1.2 billion tons of carbon dioxide [3], while according to the present behaviour of this industrial sector, 26% of carbon emission and 0.3 billion tons of crude oil consumption by the year 2025 is estimated by the study as well [3]. This is because the textile industry’s fuel consumption is not only related to the production level but also during the transfer of textile products through different transportation means to different areas [4] taking part in carbon emission. All these aspects clear the reason for being called textile industry as the most polluting industry. In Faisalabad, Pakistan, a chain of textile industries is located around the road connecting twin districts Khuranwala and Jaranwala as shown in Figure 2.

Due to industrial water waste and carbon emission, the Khuranwala/Jaranwala road of 25–28 km long is full of unbearable smell and smog. The residents and daily travellers nearby face exposure to this unhealthy environment and suffer from breathing and eye diseases. By controlling abrupt energy consumption and ways connected to pollution either directly (industrial waste) or indirectly, like nonrecyclable fabric formation, excess of textile products, and so on, can help to lessen down pollution. Several studies have been conducted to reuse industrial water waste. Nadeem et al. [5] discussed the recycling and treatment potential of textile waste water by using membrane technology. According to Dehghani and Yoo [6], the organic components and approximate temperature of the textile industry’s waste water are sufficient enough for the production of biofuel that can be used as a cheap source for creating thermal energy.

Figure 1: Textile industry processes.
Efficient consumption of energy except proper planning is not possible in the region due to the complicated nature of the textile manufacturing sector. Spinning and weaving stages fully depend on electricity, while sizing, dyeing, and rewinding requires thermal energy to heat water or to dry the fabric [7, 8]. Studies have shown that, globally one trillion KWh of electricity is consumed per year to produce 60 billion kg fabric [9]. Usage of renewable energy resources like solar energy, geothermal energy, and landfill gas is helpful in the reduction of textile production costs. It lowers the total energy per unit usage that automatically degrade the environmental pollution factor as well. In Atlanta, seven textile manufacturing plants only use renewable electricity, and 89% of this electricity is renewable source [10].

Specifically, in Pakistan, the existence of energy self-sufficient textile industries is rare. The All Pakistan Textile Mills Association (APTIMA) Punjab Chairman also insisted on adopting renewable solar energy resources to fulfill the need for electricity with affordable cost for the maintenance of industrial sustainability. According to their reporting, Pakistan textile industry is ready to shift to solar or hybrid energy generating systems [11]. This shift will not only reduce the cost but also reduce the carbon emission. In developing countries like Pakistan, where energy production is not proportional to the need, the cheap production and optimal allocation of energy is required. The usage of renewable energy resources can also be of great help for the industrial sector. Considering solar energy as a means for electricity is the best suitable option. The temperature and weather conditions of Pakistan as shown in Figure 3 can accelerate the outcome of the solar energy system. The advancement of solar energy system makes electricity production much more efficient. Using this kind of system is considered as sustainable and ecological investment. Textile industry extensively uses electricity, so the optimal utilization of energy at each stage is regarded as an important initial target.

The conventional and most widely used method with reliable results for optimization is linear programming (LP) created by Kantorovich [13]. The only drawback of LP is its nonflexibility regarding nature. Natural scenarios are full of ambiguity, while classical optimization based on LP does not cover these uncertainties. After the revelation of fuzzy sets by Zadeh [14], LP also started to be modified. Zimmerman [15] used the concept of fuzziness in LP. He invented the technique to find a solution for fuzzy multiobjective LP. The fuzziness in this technique is due to the presence of fuzzy optimization conditions in it. Atanassov [16] improved the concept of fuzziness more by introducing a new generalization of a fuzzy set named intuitionistic fuzzy set, in which both the membership grade and nonmembership grade of element from decision set are necessary. This generalization created more optimization techniques [17]. Angelov [18] made the intuitionistic fuzzy LP technique. Subsequently, several researches has appeared on intuitionistic fuzzy linear programming (IFLP). Hussain and Kumar [19] worked on intuitionistic fuzzy transportation problem (IFTP). Ebrahimnejad and Verdegay [20] worked on a fully intuitionistic transportation problem (TP).

Several optimization models for sustainable production and consumption of renewable energy are constructed using...
bilevel programming [21], mixed integer linear programming [22], simulation-optimization modelling [23], linear programming [24–26], and goal programming [27] approach. Nematian and Farzi [28] considered the case study of energy recovered from urban solid waste in Iran and developed energy and environmental management model using fuzzy LP approach. Zhou et al. [29] used type-2 fuzzy chance-constrained fractional integrated modelling method for the management of energy system subjected to uncertainties and risks. Kouaissah and Hocine [30] and Hashemizadeh and Ju [31] introduced sustainable and renewable energy portfolios using a fuzzy interval goal programming technique. Khan et al. [32] examined and assessed the optimal cost system of electricity generation for the socio-economic sustainability of India by developing a sustainable and flexible electricity generation model using flexible fuzzy goal programming. Sustainable production in the textile industry depends upon the search of sustainable ways of energy management. Emeç and Akkaya [33] developed a fuzzy optimal renewable energy model (F-OREM) to solve the energy problem involving fuzzy parameters. Abbas et al. [34] systematically analyzed the potential of cotton crop waste to synergize industrial energy systems by integrating strategic and tactical decision models into an integrated model. The results indicate that cotton crop waste is a conducive and convenient source of sustainable energy supply for the textile industry. Techato et al. [35] presented a systematic review of the optimization models used in the textile industry, mostly established for cost minimization in logistics and production and optimized mainly with linear programming, integer programming, Markov chains, genetic algorithms, and multi-objective programming. The effectiveness of the present study in contrast with conventional LP is further discussed in upcoming sections where a fully intuitionistic fuzzy energy optimization model for Pakistan’s textile industry is formed that results in optimal energy allocation that is further presented. For sustainability, the idea of replacing typical energy resources with solar energy generators along with its investing and working cost is also to be considered in reference to the existing self-sufficient textile industry of Pakistan.

3. Preliminaries

3.1. Intuitionistic Fuzzy Set. The intuitionistic fuzzy set was presented by Atanassov [16]; the degree of nonmembership and the degree of membership were expressed by the two characteristic functions. An intuitionistic fuzzy set (IFS) \( N \) in \( \mathcal{Q} \) can be described as an element of the following form \( N = \{ (s, \zeta_N(s), \eta_N(s)) | s \in \mathcal{Q} \} \) where the functions \( \eta_N: \mathcal{Q} \rightarrow [0, 1] \) and \( \zeta_N: \mathcal{Q} \rightarrow [0, 1] \) represents the degree of nonmembership and the degree of membership of the component \( s \in \mathcal{Q} \), respectively.

3.2. Triangular Intuitionistic Fuzzy Number. It is based on membership and nonmembership functions [36], considering \( Q_T = (q_1, q_2, q_3; q_1, q_2, q_3) \) such that \( q_1 \leq q_2 \leq q_3 \leq q_3 \) and its membership function is defined as

![Temperature map of Pakistan](image-url)
3.3. Arithmetic Operations. Let $Q^o_1 = (q_1, q_2, q_3; q_1, q_2, q_3)$ and $P^o_1 = (p_1, p_2, p_3; p_1, p_2, p_3)$ are two triangular intuitionistic fuzzy numbers, then the algebraic operations between them are defined as follows:

\[ Q^o_1 \oplus P^o_1 = (q_1 + p_1, q_2 + p_2, q_3 + p_3; q_1 + p_1, q_2 + p_2, q_3 + p_3) \]

\[ Q^o_1 \otimes P^o_1 = (q_1 p_1, q_2 p_2, q_3 p_3; q_1 p_1, q_2 p_2, q_3 p_3) \]

\[ \kappa Q^o_1 = (q_1 \kappa, q_2 \kappa, q_3 \kappa; q_1 \kappa, q_2 \kappa, q_3 \kappa) \text{ for } \kappa \geq 0 \]

\[ \kappa Q^o_1 = (q_1 \kappa, q_2 \kappa, q_3 \kappa; q_1 \kappa, q_2 \kappa, q_3 \kappa) \text{ for } \kappa < 0 \]

\[ Q^o_1 \otimes P^o_1 = (q_1 r_1, q_2 r_2, q_3 r_3; q_1 r_1, q_2 r_2, q_3 r_3) \]

Here,\n
\[ r_1 = \min \{q_1 p_1, q_1 p_2, q_1 p_3, q_1 p_3, q_1 p_3\} \]

\[ r_3 = \max \{q_1 p_1, q_1 p_2, q_1 p_3, q_1 p_3, q_1 p_3\} \]

\[ r_2 = q_2 p_2 = r_2 \]

\[ r_1 = \min \{q_1 p_1, q_1 p_2, q_1 p_3, q_1 p_3, q_1 p_3\} \]

\[ r_3 = \max \{q_1 p_1, q_1 p_2, q_1 p_3, q_1 p_3, q_1 p_3\} \]

In particular, if $Q^o_1$ and $P^o_1$ are two nonnegative triangular intuitionistic fuzzy numbers, then their product $Q^o_1 \oplus P^o_1$ will be \[ \{q_1 p_1, q_1 p_2, q_1 p_3, q_1 p_3, q_1 p_3\}. \]

The nonmembership function is as follows:

\[
\mu^-_{Q^o_1} = \begin{cases} 
\frac{q_2 - x}{q_2 - q_1} & q_1 \leq x < q_2 \\
1 & x = q_2 \\
\frac{q_3 - x}{q_3 - q_2} & q_2 < x \leq q_3 \\
0 & \text{otherwise.}
\end{cases}
\]

The membership function is given by

\[
y^-_{Q^o_1} = \begin{cases} 
\frac{x - q_2}{q_2 - q_1} & q_1 \leq x < q_2 \\
1 & x = q_2 \\
\frac{q_3 - x}{q_3 - q_2} & q_2 < x \leq q_3 \\
0 & \text{otherwise.}
\end{cases}
\]

With restriction $0 \leq \mu^-_{Q^o_1} + y^-_{Q^o_1} \leq 1$. If $q_1, q_2, q_3, q_1$, and $q_3$ are nonnegative, then $Q^o_1$ will be a nonnegative intuitionistic fuzzy number. The geometrical interpretation of Triangular intuitionistic fuzzy number is presented in Figure 4.

For the conversion of triangular intuitionistic fuzzy number into crisp following accuracy function [20] is used.

\[ I\left(Q^o_1\right) = \frac{1}{8}\left(q_1 + 4q_2 + q_3 + q_3 + q_3\right). \]

4. Fully Intuitionistic Fuzzy Linear Programming Model

Mathematically, a general triangular fuzzy intuitionistic energy optimization model is expressed as follows:

\[
\min \alpha = \sum_{j=1}^{m} \left[ C_j^o \Theta \xi_j \right]
\]

\[
\min \alpha = \left( \sum_{j=1}^{m} c_{j,1} x_{j,1} + \sum_{j=1}^{m} c_{j,2} x_{j,2} + \sum_{j=1}^{m} c_{j,3} x_{j,3} + \sum_{j=1}^{m} c_{j,4} x_{j,4} \right)
\]

Subjected to triangular intuitionistic fuzzy energy optimization constraints,

\[ \sum_{j=1}^{m} s_{j,1} x_{j,1} + \sum_{j=1}^{m} s_{j,2} x_{j,2} + \sum_{j=1}^{m} s_{j,3} x_{j,3} + \sum_{j=1}^{m} s_{j,4} x_{j,4} \leq \sum_{j=1}^{m} s_{j,5} x_{j,5} \]

\[ \text{...} \leq \sum_{j=1}^{m} s_{j,11} x_{j,11} \]

\[ \sum_{j=1}^{m} s_{j,12} x_{j,12} + \sum_{j=1}^{m} s_{j,22} x_{j,22} + \sum_{j=1}^{m} s_{j,32} x_{j,32} + \sum_{j=1}^{m} s_{j,42} x_{j,42} \leq \sum_{j=1}^{m} s_{j,52} x_{j,52} \]

\[ \text{...} \leq \sum_{j=1}^{m} s_{j,11} x_{j,11} \]

Here, $x_{j,1} \geq 0$. The values of $x_{j,1}$ will optimize the intuitionistic fuzzy energy cost objective function where all the $x_{j,1}$ will satisfy the nonnegativity condition and constraint equations. In the above objective function $C_j^o = (c_{j,1}, c_{j,2}, c_{j,3}, c_{j,4}, c_{j,5}, c_{j,6}, c_{j,7}, c_{j,8})$ for $j = 1, 2, 3, \ldots$ represent the triangular intuitionistic fuzzy cost coefficients and $s_{j,1}$ are the technological coefficients representing the amount of $i$ th resource consuming at rate of $x_{j,1}$ per unit where

\[ \overline{D}_j^o = \left(d_{j,1}, d_{j,2}, d_{j,3}, d_{j,4}, d_{j,5}, d_{j,6}, d_{j,7}, d_{j,8}\right) \]
refers to the total availability of the \( i \)th triangular intuitionistic fuzzy resource. For the conversion of intuitionistic fuzzy energy optimization model into linear programming problem, the accuracy function is used as defined in (4). The following equation presents the defuzzified objective function.

\[
\begin{align*}
\min & \quad \frac{1}{3} \sum_{j=1}^{m} \left( c_{j,1} x_{j,1} + 4 c_{j,2} x_{j,2} + c_{j,3} x_{j,3} + c_{j,1}^{*} x_{j,1} + c_{j,2}^{*} x_{j,2} + c_{j,3}^{*} x_{j,3} \right)
\end{align*}
\]

\[= \min \left\{ \frac{1}{3} \sum_{j=1}^{m} \left( c_{j,1} x_{j,1} + 4 c_{j,2} x_{j,2} + c_{j,3} x_{j,3} + c_{j,1}^{*} x_{j,1} + c_{j,2}^{*} x_{j,2} + c_{j,3}^{*} x_{j,3} \right) \right\}. \tag{8} \]

The above defined set of triangular intuitionistic constraints (6) can be rewritten as follows:

\[
\begin{align*}
\sum_{j=1}^{m} s_{j,1} x_{j,1} & \leq d_{1,1}, \\
\sum_{j=1}^{m} s_{j,2} x_{j,2} & \leq d_{1,2}, \\
\sum_{j=1}^{m} s_{j,3} x_{j,3} & \leq d_{1,3}, \\
\sum_{j=1}^{m} s_{j,1} x_{j,1} & \leq d_{1,1}, \\
\sum_{j=1}^{m} s_{j,2} x_{j,2} & \leq d_{1,2}, \\
\sum_{j=1}^{m} s_{j,3} x_{j,3} & \leq d_{1,3},
\end{align*}
\]

\[\tag{9} \]

The optimal solution of \( x_{j,1}, x_{j,2}, x_{j,3}, x_{j,1}^{*}, \) and \( x_{j,3}^{*} \) will be obtained by solving objective function (7) under constraints of (4).

## 5. Energy Optimization Model for Textile Industry

The textile industry is usually based on five stages which are further subdivided into several others. The main five stages are spinning, sizing, weaving, and dyeing. Each stage’s product \( (X_{i}) \) forward lessens quantity to the next stage, that is, input < output always. For example, 97% of stage 2 product is further processed for next weaving stage, and remaining 3% goes to the weaving stage whose product again becomes the input of stage 2. Considering minimum waste up to 7% for weaving stage, the material processed further is 93% of total \( x_{5} \), at the last stage, the wastage is approximately 4%. Considering a standard five stages textile model, the per month demand of stage \( x_{1}, x_{4}, \) and \( x_{5} \) products 400 units, 600 units, and 20,000 units. Per month total working hours are 720 hours [37]. The electricity cost per unit is 20.62 PKR/kWh, fuel oil is 85.68 PKR/litre, and LPG cost at the rate of 19.4103 PKR/litre [38, 39]. Energy cost for each stage is presented in Table 1.

The formulation of above model in intuitionistic fuzzy environment provided triangular intuitionistic fuzzy cost coefficients that represent the cost spent during production period as follows:

<table>
<thead>
<tr>
<th>Table 1: Energy cost in PKR.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Electricity</td>
</tr>
<tr>
<td>LPG</td>
</tr>
<tr>
<td>Furnace fuel</td>
</tr>
<tr>
<td>Total energy cost</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\tilde{C}_{i} &= \left\{ \begin{array}{l}
\tilde{C}_{1} = (46.55, 51.55, 56.55; 41.55, 51.55, 61.55), \\
\tilde{C}_{2} = (19.5653, 24.5653, 29.5653; 14.5653, 24.5653, 34.5653), \\
\tilde{C}_{3} = (36.24, 41.24, 46.24; 31.24, 41.24, 51.24), \\
\tilde{C}_{4} = (10.465, 15.465, 20.465; 5.465, 15.465, 25.465), \\
\tilde{C}_{5} = (172.892, 177.892, 182.892; 167.892, 177.892, 187.892) \end{array} \right\}
\end{align*} \tag{10} \]

The monthly triangular intuitionistic fuzzy production demand in kg for three products and total availability of working hours in a month are stated as follows:

\[
\begin{align*}
\tilde{D}_{ij} &= \left\{ \begin{array}{l}
\tilde{D}_{i} = (350, 400, 450; 300, 400, 500), \\
\tilde{D}_{i} = (550, 600, 650; 500, 600, 700), \\
\tilde{D}_{i} = (19950, 20000, 20050; 19900, 20000, 20100), \\
\tilde{D}_{i} = (670, 720, 770; 620, 720, 820) \end{array} \right\}
\end{align*} \tag{11} \]

Mathematically, intuitionistic fuzzy energy optimization is framed as follows:

\[
\begin{align*}
\min & \quad \sum_{j=1}^{m} \left( \tilde{c}_{j}^{*} \otimes \tilde{A} \right) = \left( \begin{array}{l}
(46.55, 51.55, 56.55; 41.55, 51.55, 61.55) \otimes \tilde{x}_{1}^{*} \\
(19.5653, 24.5653, 29.5653; 14.5653, 24.5653, 34.5653) \otimes \tilde{x}_{2}^{*} \\
(36.24, 41.24, 46.24; 31.24, 41.24, 51.24) \otimes \tilde{x}_{3}^{*} \\
(10.465, 15.465, 20.465; 5.465, 15.465, 25.465) \otimes \tilde{x}_{4}^{*} \\
(172.892, 177.892, 182.892; 167.892, 177.892, 187.892) \otimes \tilde{x}_{5}^{*} \end{array} \right)
\end{align*}
\]

Subject to

\[
\begin{align*}
\tilde{x}_{i} \otimes \tilde{x}_{i}^{*} & \geq (350, 400, 450; 300, 400, 500), \\
0.03 \tilde{x}_{i} \otimes \tilde{x}_{i}^{*} & \otimes 0.07 \tilde{x}_{i}^{*} = (0, 0, 0; 0, 0, 0), \\
0.97 \tilde{x}_{i} \otimes \tilde{x}_{i}^{*} & = (0, 0, 0; 0, 0, 0), \\
0.93 \tilde{x}_{i} \otimes \tilde{x}_{i}^{*} & \geq (0, 0, 0; 0, 0, 0), \\
0.96 \tilde{x}_{i} & \geq (19950, 20000, 20050; 19900, 20000, 20100), \\
0.007 \tilde{x}_{i} \otimes 0.007 \tilde{x}_{i}^{*} \otimes 0.013 \tilde{x}_{i}^{*} \otimes 0.0062 \tilde{x}_{i}^{*} \leq (670, 720, 770; 620, 720, 820), \\
\tilde{x}_{i} & \geq (0, 0, 0; 0, 0, 0), i = 1, 2, 3, 4, 5,
\end{align*}
\]

\[\tag{12} \]
According to the above intuitionistic model, this formulated intuitionistic fuzzy energy optimization model is defuzzified as follows:

\[
\begin{align*}
\min \ &= \ \frac{1}{8} \left[ 46.55x_{1,1} + 4 \times 51.55x_{1,2} + 56.55x_{1,3} + 41.55x_{1,4} + 61.55x_{1,5} \right] \\
+ \ &\frac{1}{8} \left[ 19.5653x_{2,1} + 4 \times 24.5653x_{2,2} + 29.5653x_{2,3} + 14.5653x_{2,4} + 34.5653x_{2,5} \right] \\
+ \ &\frac{1}{8} \left[ 36.24x_{3,1} + 4 \times 14.24x_{3,2} + 46.24x_{3,3} + 31.24x_{3,4} + 51.24x_{3,5} \right] \\
+ \ &\frac{1}{8} \left[ 10.465x_{4,1} + 4 \times 15.465x_{4,2} + 20.465x_{4,3} + 5.465x_{4,4} + 25.465x_{4,5} \right] \\
+ \ &\frac{1}{8} \left[ 174.892x_{5,1} + 4 \times 177.892x_{5,2} + 182.892x_{5,3} + 167.892x_{5,4} + 187.892x_{5,5} \right].
\end{align*}
\]

Subject to

\[
\begin{align*}
x_{i,1} &\geq 0, x_{i,2} \geq 0, x_{i,3} \geq 0, x_{i,4} \leq 0, x_{i,5} \leq 0 & \text{where} \ i = 1, 2, 3, 4, 5 \\
0.007x_{1,1} - 0.007x_{3,1} + 0.01x_{4,1} + 0.006x_{5,1} &\leq 670, \\
0.007x_{1,2} - 0.007x_{3,2} + 0.01x_{4,2} + 0.006x_{5,2} &\leq 720, \\
0.007x_{1,3} - 0.007x_{3,3} + 0.01x_{4,3} + 0.006x_{5,3} &\leq 770, \\
0.007x_{1,4} - 0.007x_{3,4} + 0.01x_{4,4} + 0.006x_{5,4} &\leq 620, \\
0.007x_{1,5} - 0.007x_{3,5} + 0.01x_{4,5} + 0.006x_{5,5} &\leq 820, \\
x_{1,1} - x_{3,1} &\geq 350, \\
x_{1,2} - x_{3,2} &\geq 400, \\
x_{1,3} - x_{3,3} &\geq 450, \\
0.03x_{1,1} - x_{3,1} + 0.07x_{4,1} &= 0, \\
0.03x_{1,2} - x_{3,2} + 0.07x_{4,2} &= 0, \\
0.03x_{1,3} - x_{3,3} + 0.07x_{4,3} &= 0, \\
0.03x_{1,4} - x_{3,4} + 0.07x_{4,4} &= 0, \\
0.03x_{1,5} - x_{3,5} + 0.07x_{4,5} &= 0, \\
x_{1,1} - x_{3,1} &\leq 300, \\
x_{1,2} - x_{3,2} &\leq 500, \\
x_{1,3} - x_{3,3} &\leq 500, \\
0.97x_{1,1} - x_{3,1} &= 0, \\
0.97x_{1,2} - x_{3,2} &= 0, \\
0.97x_{1,3} - x_{3,3} &= 0, \\
0.97x_{1,4} - x_{3,4} &= 0, \\
0.97x_{1,5} - x_{3,5} &= 0, \\
0.93x_{1,1} - x_{3,1} &\leq 550, \\
0.93x_{1,2} - x_{3,2} &\leq 600, \\
0.93x_{1,3} - x_{3,3} &\leq 650, \\
0.93x_{1,4} - x_{3,4} &\leq 650, \\
0.93x_{1,5} - x_{3,5} &\leq 700, \\
0.96x_{1,1} &\geq 19950, \\
0.96x_{1,2} &\geq 20000, \\
0.96x_{1,3} &\geq 20050, \\
0.96x_{1,4} &\geq 19900, \\
0.96x_{1,5} &\geq 20100.
\end{align*}
\]

The optimal solution of (13) is

\[
\begin{align*}
x_1 &= (24111.7, 24159.4, 24207.1, 24064, 24159.4, 24254.8), \\
x_2 &= (23757.1, 23759.4, 23761.7, 23754.8, 23759.4, 23764), \\
x_3 &= (874.161, 874.107, 874.054, 874.125, 874.107, 874), \\
x_4 &= (23048.8, 23046.6, 23044.4, 23051.1, 23046.6, 23024.1), \\
x_5 &= (20781.3, 20833.3, 20885.4, 20729.2, 20833.3, 20937.5).
\end{align*}
\]

(16)

By substituting the values of \(x_i\)'s in objective function (10), the minimal triangular intuitionistic fuzzy energy cost is calculated as follows:

\[
\begin{align*}
\min \gamma &= \left( \sum_{i=1}^{5} C_i x_i \right) = (5463813.64, 5927615.1, 6403249.54; \\
4979403.76, 5927615.1, 7880260.7)
\end{align*}
\]

(15)

5.1. Postoptimal Analysis. Table 2 elaborates the flexibility of the presented model in intuitionistic fuzzy environment. Within the provided range for each variable, the model remains
optimal and feasible. Since $x_i^y = (x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5})$; therefore, the allowable change in $x_{i,j}$ will vastly the range for $x_i^y$ as well. This change will not impact the feasibility of the given model.

As shown in Table 3, the optimal results changed accordingly within the limits without impacting feasibility. The limit report of this model provided lower limit and upper limit for each decision variable along with its corresponding objective value.
objective values. As the main objective is to minimize the energy cost, so here the optimal result is totally based on the lower limits to obtain minimum output. Whereas the upper limit is providing the range for feasible solution. Table 4 presents the sensitivity report for the constraint equation. As there is not always perfect availability of resources and time so for each situation making new model is not possible. The following report allows us to predict the flexibility regarding

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the optimal and feasible results we could have obtained if the availability of resources fluctuate between the allowable increase and decrease.

5.2. Comparison. The solution of linear optimization problem under consideration is carried out by already existing linear programming (LP) and fuzzy linear programming techniques (FLP). The objective function value for the proposed method is less than LP and FLP techniques. The results are presented in Table 5.

From Figure 5, the degree of acceptance (rejection) of energy cost per month increases (decreases) from 5463813.64 to 5927615.1 and decrease (increases) from 5927615.1 to 6403249.54, while 5927615.1 is considered as required value where the level of acceptance is fully satisfied and degree of rejection is fully zero. The optimal solution of linear programming and fuzzy linear programming whose resulting cost are PKR 5987499 per month and 5980612.1 per month, while for proposed method it is 5927615.1 per month. This is evident that the fully intuitionistic fuzzy optimization model is more effectively minimize the energy cost as compared to linear programming approach.

6. Conclusion

Since Pakistan has a huge textile industrial sector and is now facing so many uncertainties due to the unpredicted policy shift 2020–25, therefore economically improving this sector will help every person belonging to the textile industry’s hierarchy from consumers, labourers to stakeholder, and government. In Pakistan, government suggests industries to have a local supply of gas, which will create an explosion in production costs. According to the executive director of all Pakistan mills associations (APTAMA), the textile industry will face a 50% increase in the production cost [40]. The best option for Pakistan’s industrial sector is to become self-sufficient as soon as possible. For this purpose, they need to change their habit of being dependent on the government for their energy resources. It is only possible to shift their energy modes from nonrenewable to renewable ones for sustainable energy production. According to regional temperature conditions of Pakistan as shown in Figure 2, solar energy production refines option. Since Pakistan’s Kohinoor Textile Mills (KTML) in Rawalpindi, Pakistan, converted to a 6 Mw solar power plant with Reon energy making it affordable, sustainable, and more competitive. The implementation of
this solar plant resulted in cost reduction and carbon footprint reduction. Because of its success, further three projects are also covered by KTML from 2017 to 2019, and their captive solar plant is saving almost 30% energy as well [41]. Therefore in Punjab, Pakistan, where there is a hub of textile industries should take a step forward towards the solar power plants.

The application of this solar plant project approximately requires 65 to 80 million in Pakistan. This project will contain a one Mw system that can produce 5000 units per day if minimum five hours of sunlight is considered. Monthly electricity unit production from this system will approximate between 150000 kWh and 180000 kWh. If LP solution is considered, the electricity unit per month consumed by all stages are 109108.6563 kWh and from FIFLP 106204.7783 kWh. In both cases, monthly electricity unit production through a solar plant is greater than need. The remaining electricity units can be sold out to the government or nearby industries that will accelerate to overcome the investing cost and the amount obtained from sold electricity can be further used for maintenance purpose as well. Decision making through FIFLP provide more flexible and optimal outputs. The less units industry will consume the more will be available for sale and soon the invested cost will overcome and providing profit. The conversion of few Pakistan’s textile industry on solar power plants will help their neighboring industries, because the electricity cost per unit in solar generators is cheaper than other. That is, the government provide electricity at the rate of 20.62 Rs/Kwh while solar generating electricity cost is between 8 and 14 Rs/kWh.

The idea of intuitionistic fuzzy model helps in sufficient allocation of energy units that provides less wastage of energy. The implementation of this modelling can definitely lower down the production cost. For pilot study the implementation of sustainable energy optimization model on one of the industry from that region mentioned in Figure 1 can provide fruitful results along with the optimizing production cost of the neighboring industries as well.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there were no conflicts of interest regarding the publication of this article.

Authors’ Contributions

All authors contributed equally to the preparation of this manuscript.

References


