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A synergistic energy and production supply chain network design and planning optimization model considering multi-product and multi-periods

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ABSTRACT

Undoubtedly, there is a permanent and extreme importance to production planning to ensure that the necessary resources are provided on time so as not to disrupt production. One of the most important of these resources is energy, which is no less important than raw materials. Therefore, it was decided in this research to develop an integrated mathematical model for production and energy planning optimisation model for supply chain networks in case of multi-product and multi-periods. The primary aim is to optimise supply, production, distribution, and inventory planning for a supply chain consisting of three suppliers, one factory, three distributors, and four retailers to maximise profit. The proposed model was formulated using mixed-integer linear programming and solved using LINGO 18.0 software. Further, the efficiency of this model was verified by solving and analysing the results of a comprehensive example: different scenarios representing a market with different demand patterns and two cases with different parameters. The results indicated that the proposed model succeeded in achieving high profits while controlling the amount of energy consumed by the factory during manufacturing, as well as in solving production planning problems.

Keywords: Energy; Production; Planning; Multi-products; Multi-periods; MILP; LINGO.

1. INTRODUCTION

Supply chain networks can be modelled to aid in making decisions about location, transportation, and inventory. This study contributed to the development of CLSC design standards that can be applied to various products [1].

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Poor production planning may have a negative impact on company profit and customer satisfaction [2]. Buildings consume a large amount of energy and the best way to reduce energy use is to improve the energy efficiency of the existing buildings [3].

Both large and small production planning can be performed using a simple data model. The product's work plan now includes information on the amount of energy required. Data must be accurate in a 15-min time frame for detailed planning [4]. The average amount of energy used in a work sequence can be determined by examining the power demand capacity and cycle-time data. People who desire to make dark-coloured objects can now use new energy data to help them design them [5], [6].

With the growth of the global economy, companies have been forced to interact with the supply chain rather than operating on their own. New forest-based biorefinery supply chains have considered various employment types and locales [7]. The development of new jobs is correlated with a decrease in greenhouse-gas emissions. The primary objective of this investigation was to develop an analytical framework to quantify the environmental performance of industrial supply chains. In addition, the analytical hierarchy process (AHP) is used to evaluate and compare the performance of the GSCs[8].

Energy-based models can be used in hierarchical production planning to identify similar problems [9], where profit, total cost, and customer happiness are the main goals [10]. The two primary purposes of supply management processes are the total reduction in supply chain costs and improvement in the average amount of things delivered to clients [11]. The two primary objectives of the model are to minimise the total costs and maximise the overall greenness score of the raw materials and components. The greenness of each supplier is assessed using the fuzzy EDAS approach [12]. Wang et al. [13] built a supply chain that maximised profit while considering capacity constraints.

In process industries, energy is often considered the primary source of work power, and this dissertation examined certain most crucial elements. Process industries such as chemicals, pulp, and steel are the focus of these cases [14], [15]. As a renewable energy source, biomass is an essential link in the sustainability chain. However, most companies, particularly small and medium-sized enterprises (SMEs), encounter difficulties and hostility when attempting to save energy. The approach used to determine the most efficient way to generate electricity from biomass is sufficient to solve this problem [16], [17]. Al-Ashhab proposed a method to solve partner selection and production planning problems in manufacturing chains [18] [19] considering the network shown in figure 1.

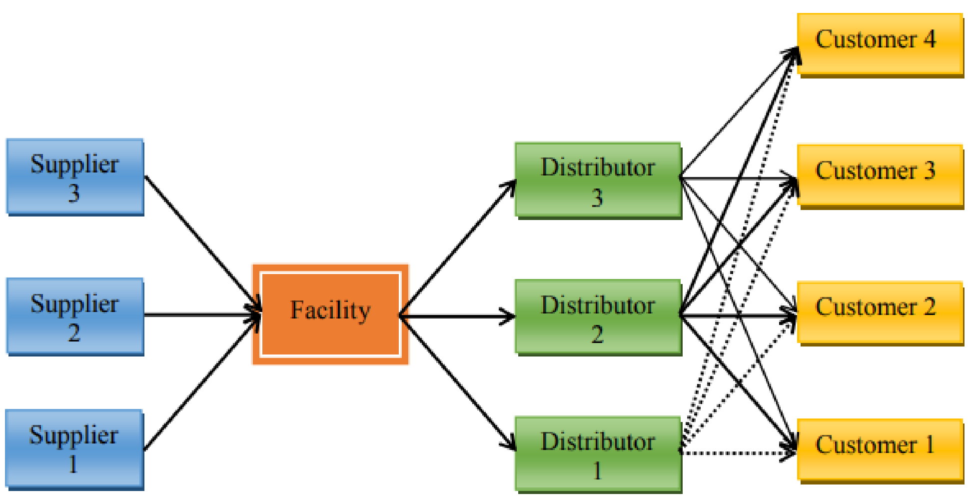

Figure 1: Facility, suppliers, distributors, and customer network [3].

This research is focused on developing an integrated energy supply chain and production planning employing multi-period and multi-product using the LINGO programming language, solving optimisation problems, and a perfect model for the three distributors, one factory, two power stations, three suppliers, four customers, three products, and twelve periods. This software is expected to enable businesses to maintain a record of their supply chains as well as their production strategy. However, the new product will be more useful than in previous studies and will have better products and profitability.

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Problem Discerption

In this model, a production plan was developed for a factory and its production was linked to the amount of energy consumed in each period. The factory receives raw materials from well-known suppliers and produces several products with a known manufacturing capacity and known storage capacity. These products are distributed by distributors in periods specific to the required customers. Everything related to this process was defined, and the quantities, capacities, costs, and distances between the parties and their relationship to each other were defined as well.

The model attempted to create the highest possible profitability and the best level of service by satisfying customer needs, reducing the required costs, and choosing the most appropriate distributors to provide the nearest and closest customers. Further, it deals with shortage, manufacturing, and storage costs, as well as increasing profits when factory electricity is economically consumed to reduce costs. Moreover, the model functioned in accordance with the restriction set and the capabilities of the concerned parties and designer.

One of the most important parts of this work was connecting two power plants to the specified factory, determining the capacity of each station, studying the electricity consumption and its cost according to the production of the factory, and clarifying the relationship between them. This was to determine the best productive economic model for the factory at the lowest costs with a high level of customer service and high profits, which is the main goal of any business or company.

The proposed model is formulated as mixed-integer linear programming (MILP) and solved by the LINGO 18.0 software.

Figure 2 shows the components and network of this study, which consists of one facility with three suppliers and two power stations. The facility distributes the three distributors, following which the three products to the three distributors reach the four customers in twelve periods.

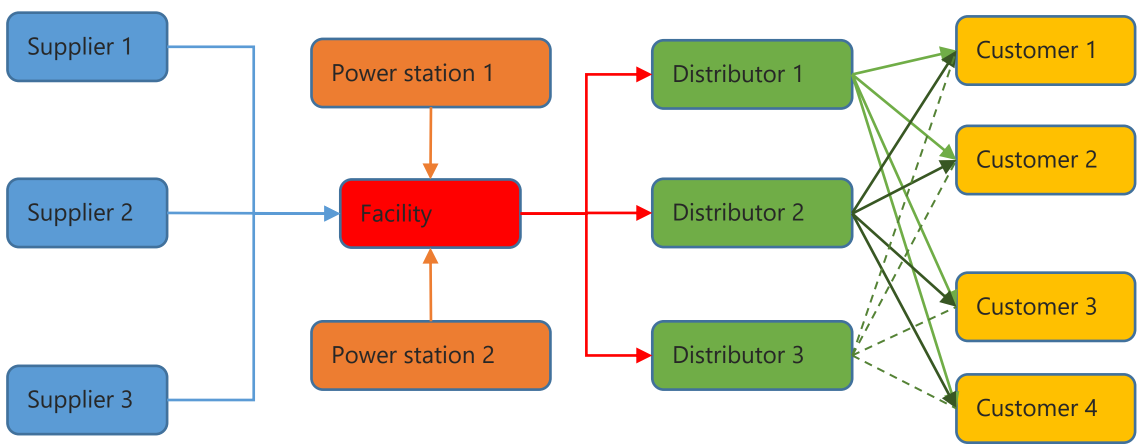

Figure 2 Supply chain network

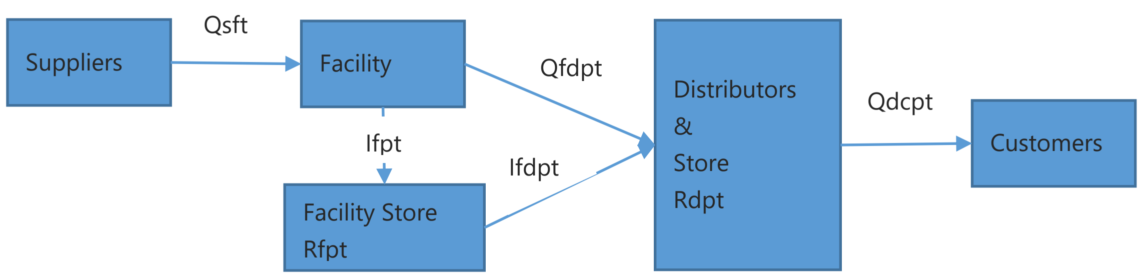

Figure 3 Model Flow

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Figure 3 shows the flow of raw materials from their beginning to their arrival as products for customers. Suppliers are responsible for providing raw materials for the facility. Further, the facility manufactures materials, converts them into products, and then distributes the products to distributors. Moreover, the facility can store certain products in its own warehouse to achieve better and distribute the products to customers or store them according to the demands of the customer.

Model Assumptions and limitations

The following assumptions were considered to develop this model:

a. Energy consumption should be limited to the volume of production of the facility.

b. The capacity of each power station is limited.

c. The value of energy consumption is related to the size of the quantities used to produce each product for each period.

d. The consumption cost is related to the amount of energy consumed by the factory for each product in each period.

e. The model contained multiple products (three products), different weights for each product, and the quantities of raw materials from which the products were made were specified and transferred from the supplier to the factory.

f. The model was multi-period and had all twelve specified periods.

g. The distances of the sites in this model were specified for all parties from and to each other (customers, suppliers, factories, and distributors).

h. Customer demand is known for all three products in all twelve periods.

i. The types of costs are known and include electric energy, fixed, material, manufacturing, nonutilized capacity, shortage, transportation, and inventory holding costs, which are known for each location and for each product in each period.

j. The manufacturing hour capacity of the facility was defined.

k. The raw material storage capacity of the facility was defined.

l. The storage capacity of the products in the facility was defined.

m. The capacity and storage costs of the three distributors were defined.

n. The capacity of the three suppliers was defined.

o. The shortage cost depended on the difference in the quantities required by customers and the quantity transferred from distributors to customers in each period for each product.

p. The cost of maintaining the product depended on the weight of the product and the stock left in each period in the factory and in the distributor.

q. The cost of transportation depends on the weight of the quantities transferred. The values were calculated for all the products in each period.

r. The cost of unused capacity depended on the difference between the factory manufacturing capacity, quantities exported from the factory, and quantities stored in the factory.

s. The manufacturing cost depended on the number of quantities exported from the factory to the distributors, the number of quantities stored in the factory, and the time and cost of manufacturing the product within the factory in each period and each product.

t. The material cost of the product depended on the amount of raw material and size of the product.

u. All batch values exported and stored from and to anywhere must be integers only.

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2. MODEL FORMULATION

Model sets, parameters, and variables

Sets:	
F	facilities
D	potential Distributors
S	potential suppliers
C	Customers
P	Product
T	Period
W	power stations
Parameters:	
$ECPU_w$	Energy cost per unit.
$ECPH_f$	Energy consumption per hours for facility f,
CAPWT	Power station w in periods t,
Bdp	Batch size of distributor d for product p,
Wp	Weight of the product p (kg/unit),
$DEMAND_{cpt}$	Demand of customer c from product p in period t,
P_{pct}	Unit price of product p in period t for customer c,
$MATCOST_{st}$	Material cost per unit of supplier s in period t,
B_s	Batch size of supplier s,
B_{fp}	Factory batch size f for product p.
MC_{ft}	Manufacturing cost for factory f at period t ($/hr),
MH_p	Manufacturing time for product p (hr / unit),
$CAPH_{ft}$	Manufacturing capacity of facility f at period t,
CAP_{st}	Capacity of supplier s at period t (kg),
CAP_{dt}	Distributor d capacity at period t (kg),
$CAPFS_{ft}$	Storing capacity of facility f at period t (kg),
$CAPM_{ft}$	Material storage capacity of the facility f in period t (kg),
$SCPU_p$	Shortage cost per period for product p ($/period),
$NUCC_f$	Cost of non-utilized manufacturing capacity of the facility f ($/hr),
TC_{perkm}	Transportation cost ($/unit/km),
D_{ij}	Distance between location I and location j.
$F_{s,d,f}$	Fixed cost of supplier s, distributor d, and facility f
HF_f	Factory holding cost
HD_d	Distributor holding cost
S	Small number.
M	Big number.
Decision variables:	
Q_{dcpt}	Number of batches transported from distributor d to customer c for product p in period t,
Q_{fdpt}	Number of batches transported from the facility to the distributor d for product p in period t,
Q_{sft}	Number of batches transported from supplier s to the facility in period t,
QE_{wft}	Quantity of energy feeding from power station w to the facility f in periods t,
I_{fpt}	Number of batches transported from the facility to its store for product p in period t,
I_{fdpt}	Number of batches transported from the facility to distributor d for product p in period t,
L_i	The binary variable is equal to 1 if a location i is open and equal to 0 otherwise.

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R_{dpt}	Residual inventory of the period t in the distributor d for the product p.
R_{fpt}	Residual inventory of the period t at store of the facility for product p.

Objective Function

The objective is to achieve the maximum possible profit for the optimised situation of this model and to apply the required equations and constraints, as shown in Equation (1).

$$\text{Profit} = \text{Total Revenue} - \text{Total Costs.} \qquad (1)$$

Total Revenue

This is the total quantity distributed from distributors to customers, multiplied by the price of the product and batch size, each according to the product and period. which are shown in equation (2).

$$\text{Total Revenue} = \sum_{d\in D}(\sum_{c\in C}(\sum_{p\in P}(\sum_{t\in T}(Q_{dcpt} * B_{dp} * P_{pct})))) \qquad (2)$$

Total Cost

It is the summation of all the costs considered and paid in the process of this model. and are shown in (3).

$$\text{Total Costs} = \text{Fixed Cost} + \text{Material Cost} + \text{Manufacturing Cost} + \text{Inventory Holding Cost} + \text{Transportation Cost} + \text{Shortage Cost} + \text{Non Utilized Capacity Cost} + \text{Energy Costs} \qquad (3)$$

The fixed cost is the cost of contracting with the facility, supplier, and distributor with the binary variable of each, as shown in Equation (4).

$$\text{Fixed Cost} = \sum_{s\in S}(F_s * L_s) + \sum_{f\in F}(F_f * L_f) + \sum_{d\in D}(F_d * L_d) \qquad (4)$$

The raw material cost is the total batch size transferred from the suppliers to the facility during all periods, as shown in Equation (5).

$$\text{Material Cost} = \sum_{f\in F}(\sum_{s\in S}(\sum_{t\in T}(Q_{sft} * B_s * MATCOST_{st}))) \qquad (5)$$

The manufacturing cost is the batch size of manufactured in all periods and stored quantities from the second period to the last in the factory, the hours, and the cost of manufacturing them, as shown in Equation (6).

$$\text{Manufacturing Cost} = \sum_{f\in F}(\sum_{d\in D}(\sum_{p\in P}(\sum_{t\in T}(Q_{fdpt} * B_{fp} * MH_p * MC_{ft})))) + \sum_{p\in P}(\sum_{t\in 2\ldots T}(I_{fpt} * B_{fp} * MH_p * MC_{ft})) \qquad (6)$$

The cost of non-utilized capacity is the manufacturing cost of the difference between the manufacturing capacity and the total quantities manufactured and stored in the facility, as shown in Equation (7).

$$\text{Non Utilized Capacity Cost} = \sum_{f\in F}((\sum_{t\in T}(\sum_{p\in P}((CAPH_{ft} * L_f - \sum_{d\in D}(Q_{fdpt} * B_{fp} * MH_p) - \sum_{d\in D}(I_{fpt} * B_{fp} * MH_p)))) * NUCC_f)) \qquad (7)$$

The shortage cost is the difference between the customer demand product quantity and the distributed product quantity from the distributors to the customers, as shown in Equation (8).

$$\text{Shortage Cost} = \sum_{p\in P}(\sum_{c\in C}(\sum_{t\in T}((\sum_{1}^{t}(DEMAND_{cpt}) - \sum_{1}^{t}(\sum_{d\in D}(Q_{dcpt} * B_{dp})))) * SCPU_p) \qquad (8)$$

The transportation cost is the cost of transporting all the weights of the quantities, starting from the raw materials to the factory and after their manufacture, from the factory to distributors, and from distributors to customers, with defined distances between each part and the other, and the cost of transport per kilometre, as shown in Equation (9).

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Transportation Cost

$$= \sum_{s\in S}(\sum_{f\in F}(\sum_{t\in T}(Q_{sft} * B_s * TC_{perkm} * D_{sf}))) + \sum_{f\in F}(\sum_{d\in D}(\sum_{p\in P}(\sum_{t\in T}(Q_{fdpt} * B_{fp} * W_p * TC_{perkm} * D_{fd}))))$$
$$+ \sum_{f\in F}\sum_{p\in P}\sum_{t\in T}(I_{fpt} * B_{fp} * W_p * small))) + \sum_{f\in F}(\sum_{d\in D}(\sum_{p\in P}(\sum_{t\in T}(\sum_{t=2}^{T}(I_{fdpt} * B_{fp} * W_p * TC_{perkm} * D_{fd})))))$$
$$+ \sum_{d\in D}(\sum_{c\in C}(\sum_{p\in P}(\sum_{t\in T}(Q_{dcpt} * B_{dp} * W_p * TC_{perkm} * D_{dc})))) \quad 9$$

The holding cost is shown in Equation (10).

$$\text{Inventory Holding Cost} = \sum_{f\in F}(\sum_{p\in P}(\sum_{t\in T}(R_{fpt} * W_p * HF_f))) + \sum_{d\in D}(\sum_{p\in P}(\sum_{t\in T}(R_{dpt} * W_p * HD_d))) \quad 10$$

The energy cost is the amount of electricity consumed by the facility provided by the two power stations to produce the production, as shown in Equation (11).

$$\text{Energy Cost} = \sum_{w\in W}(\sum_{f\in F}(\sum_{t\in T}(QE_{wft} * ECPU_w))) \quad 11$$

Constraints

There are two types of constraints to ensure balancing of the flow and capacity limits of facilities.

Balance Constraints

Constraints (12 – 21) maintain the balance between each part to others.

$$\sum_{s\in S}(Q_{sft} * B_s) = \sum_{d\in D}(\sum_{p\in P}(Q_{fdpt} * B_{fp} * W_p)) + \sum_{p\in P}(I_{fpt} * B_{fp} * W_p), \forall t \in T, \forall f \in F \quad 12$$

$$I_{fp(t=1)} * B_{fp} = R_{fp(t=1)} * B_{fp}, \forall p \in P, \forall f \in F \quad 13$$

$$(I_{fpt} * B_{fp}) + (R_{fp(t-1)} * B_{fp}) = (R_{fpt} * B_{fp}) + \sum_{d\in D}(I_{fdpt} * B_{fp}), \forall t \in 2 \to T, \forall p \in P, \forall f \in F \quad 14$$

$$(\sum_{d\in D}(I_{fdpt})) \leq R_{fp(t-1)}, \forall t \in 2 \to T, \forall p \in P, \forall f \in F \quad 15$$

$$\sum_{f\in F}(Q_{fdp(t=1)} * B_{fp}) = R_{dp(t=1)} * B_{dp} + \sum_{c\in C}(Q_{dcp(t=1)} * B_{dp}), \forall d \in D, \forall p \in P \quad 16$$

$$I_{fdp(t=1)} = 0, \forall f \in F, \forall d \in D, \forall p \in P \quad 17$$

$$\sum_{f\in F}((Q_{fdpt} + I_{fdpt}) * B_{fp}) + (R_{dp(t-1)} * B_{dp}) = R_{dpt} * B_{dp} + (\sum_{c\in C}(Q_{dcpt} * B_{dp})), \forall t \in 2 \to T, \forall d \in D, \forall p \in P \quad 18$$

$$(Q_{fdpt} + I_{fdpt}) * B_{fp} = TQ_{fdpt} * B_{fp}, \forall f \in F, \forall d \in D, \forall p \in P, \forall t \in T \quad 19$$

$$\sum_{d\in D}(\sum_{1\to t}(Q_{dcpt} * B_{dp})) \leq \sum_{1\to t}(DEMAND_{cpt}), \forall t \in T, \forall c \in C, \forall p \in P \quad 20$$

$$\sum_{w\in W}(QEwft) = \sum_{d\in D}(\sum_{p\in P}(Q_{fdpt} * B_{fp} * MH_p * ECPH_f)) + \sum_{p\in P}(I_{fpt} * B_{fp} * MH_p * ECPH_f)) , \forall f \in F, \forall t \in T \quad 21$$

Capacity constraints

Constraint (22 – 27) ensure that the quantities transferred to each facility does not exceed its capacity.

$$\sum_{f\in F}(Q_{sft} * B_s) \leq CAP_{st} * L_s, \forall t \in T, \forall s \in S \quad 22$$

$$\sum_{s\in S}(Q_{sft} * B_s) \leq CAPM_{ft} * L_f, \forall t \in T, \forall f \in F \quad 23$$

$$(\sum_{d\in D}(\sum_{p\in P}(Q_{fdpt} * B_{fp} * MH_p)) + \sum_{p\in P}(I_{fpt} * B_{fp} * MH_p)) \leq CAPH_{ft} * L_f , \forall t \in T, \forall f \in F \quad 24$$

$$\sum_{p\in P}(R_{fpt} * B_{fp} * W_p) \leq CAPFS_{ft} * L_f, \forall t \in T, \forall f \in F \quad 25$$

$$\sum_{f\in F}(\sum_{p\in P}((Q_{fdp(t=1)} + I_{fdp(t=1)}) * B_{fp} * W_p)) \leq CAP_{d(t=1)} * L_d, \forall d \in D \quad 26$$

$$\sum_{f\in F}(\sum_{p\in P}((Q_{fdpt} + I_{fdpt}) * B_{fp} * W_p)) + \sum_{p\in P}(R_{dp(t-1)} * B_{fp} * W_p) \leq CAP_{dt} * L_d, \forall t \in 2 \rightarrow T, \forall d \in D \quad 27$$

Constraint (28) ensures that the amount of energy consumed from the power stations in the facility does not exceed the power station capacities.

$$\sum_{f\in F}(QEwft) \leq CAPWT , \forall w \in W, \forall t \in T \quad 28$$

Computational Results and Analysis

After writing the code using LINGO 18.0, and entering all the data, equations, and constraints, multiple scenarios were assumed to test the code's logicality and functionality.

The results of the LINGO 18.0 program were obtained, which were then verified by entering them into Microsoft Excel to analyse and represent them in arranged graphs and tables.

Input data

Table 1 shows the fixed values that did not change in the two scenarios.

Table 1. Input fixed data for different parameters.

No	Input parameter	Values	Units
1	F	1	
2	D	3	
3	S	3	
4	C	4	

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5	P	3	
6	T	12	
7	SMAX	3	
8	DMAX	3	
9	W	2	
10	TCperkm	0.001	($/unit/km)
11	M	9000000	
12	small	1	
13	Ff	50000	($)
14	NUCCf	2	($/hr)
15	HFf	10	($/unit)
16	HDd	10	($/unit)
17	ECPHf	0.5	($/hr)
18	CAPst	20000	(kg)
19	CAPMft	20000	(kg)
20	CAPHft	20000	(kg)
21	CAPFSft	10000	(kg)
22	CAPdt	10000	(kg)
23	MATCOSTst	10	($/hr)
24	MCft	10	($/hr)
25	Bdp	1	
26	$ECPU_{w12}$	0.18 0.2	($/kW)
27	$CAPW_{12}T$	5000 6000	(kW)
28	$SCPU_{p123}$	1 2 3	($/period)
29	F_{s123}	20000 20000 20000	($)
30	F_{d123}	20000 20000 20000	($)
31	W_{p123}	1 2 3	(kg/unit)
32	MH_{p123}	1 2 3	(hr / unit)
33	B_{s123}	10 10 10	
34	B_{fp123}	10 10 10	
35	$D_{s123}f$	50 60 70	(Km)
36	D_{fd123}	50 60 70	(Km)
37	$P_{p123}ct$	100 150 200	($)
		50 60 70 80	
38	Ddc	60 50 60 70	(Km)
		70 60 50 60	

The demands of the customers are an input value for each period, as shown in figure 4 and are different between the two scenarios.

The first scenario started with a few values of customer demand and then increased by a fixed amount in each period until it reached periods 6 and 7, with the same values. Thereafter, it decreased by a fixed amount. This scenario is referred to as 'Increase Quadratically Relationship'. The second scenario is the opposite of the first, where the customer's needs start in large quantities and then decrease by a fixed amount. The demand for quantity in periods 6 and 7 was at the lowest levels. This scenario is referred to as 'Decrease Quadratically Relationship'.

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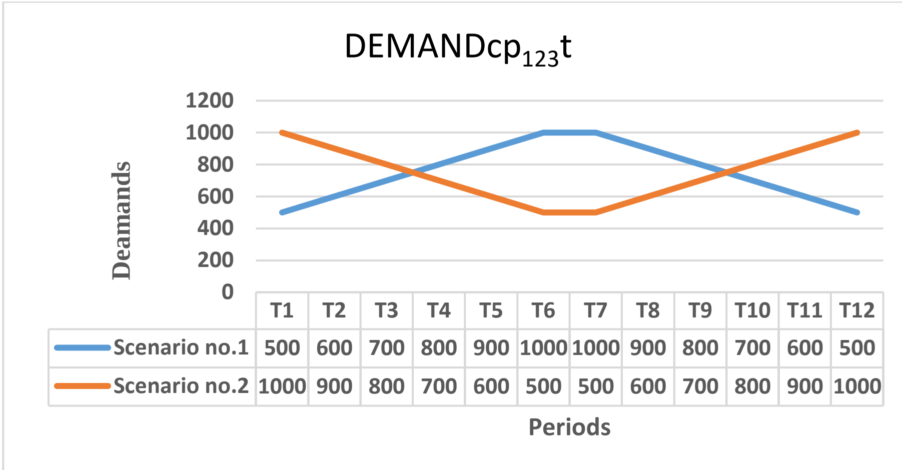

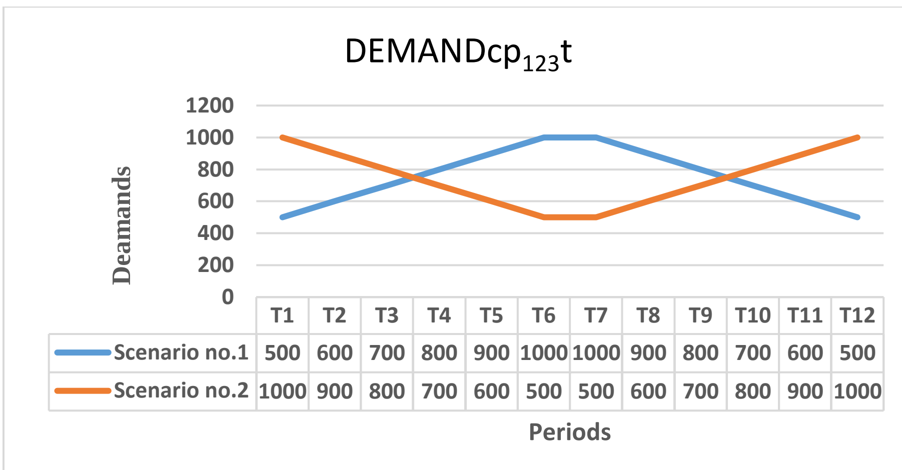

Figure 4 Distribution of the graph and Input Values of demand for each customer in all periods for all products in Scenario 1 and 2.

From these two scenarios, the performance of the model parts (suppliers, power stations, facilities, distributors, and customers) can be examined when the values are high in the middle and customer demand is low in the terminal periods.

3. RESULT AND DISCUSSION

The results were verified and clarified as below, considering that the difference between the scenarios was only in the customers' demand for quantities.

Scenario 1

The tables and graphics below show the results for the first scenario. The quantities transferred from one party to another, quantities stored in the warehouses, energy quantities supplied to the factory, costs that have been paid, profits, and other aspects are shown.

Figure 5 shows the percentage of each type of cost compared with the total cost.

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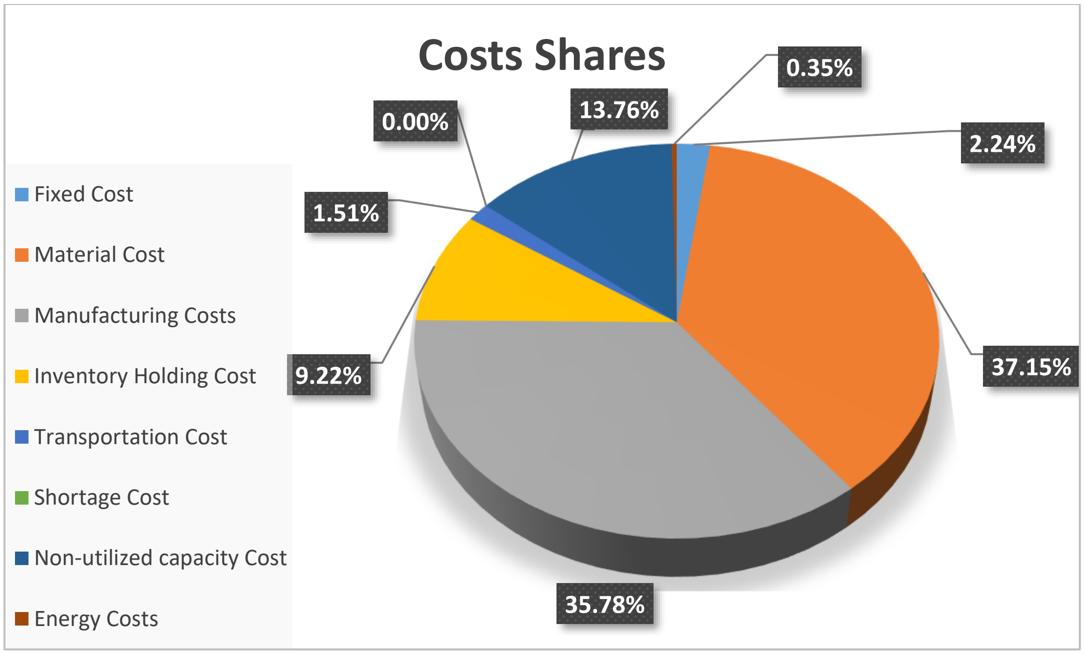

Figure 5 Costs Shares in Scenario 1.

Figure 5 indicates that:

- Very high profits compared to the types of costs that have been paid.
- The cost of materials was the highest of all costs.
- The cost of manufacturing was very close to the cost of materials, which together constituted more than half of the considered costs.
- There is no value for the shortage cost, which indicates that there is no shortage of products, that all the needs of customers have been satisfied, and that the level of customer service is 100% for all customers.
- The cost of energy was the lowest cost paid in this model, which indicates the success of the model in the energy economy.

From Figure 6, it is clear that:

- The demand was increasing linearly.
- Production reached the highest manufacturing capacity of the facility, except in the second period.
- There were no shortages of quantities in the first six periods.
- Certain products were stored in the factory warehouse and the distributor warehouse.

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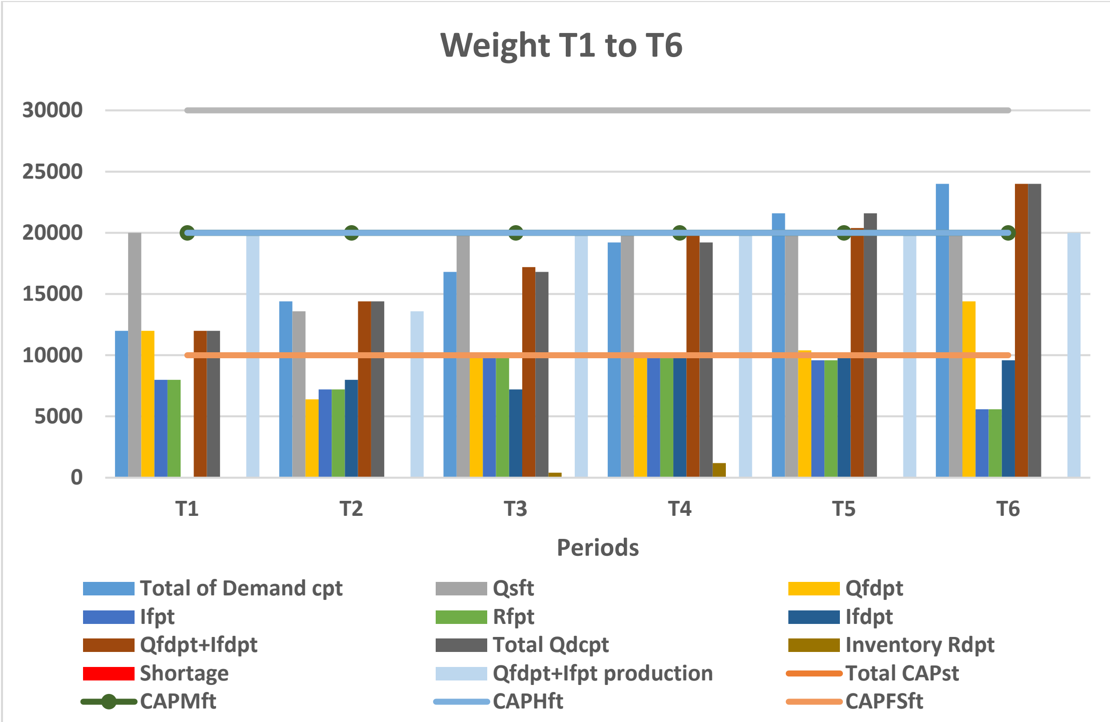

Figure 6 General flow of weights period 1 to 6 for everything related to the batch size in scenario 1.

From Figure 7, it becomes clear that:

- Production and demand decreased linearly.
- Production reached the highest manufacturing capacity of the facility only in periods 7 and 8. Subsequently, it decreased.
- There were no shortages or distributors' residual inventory of quantities ranging from 7 to 12 periods.
- No products were stored in the factory warehouse or distributor's warehouse, except for period no. 7.
- all the demands were achieved completely.

Figure 8 shows the relationship between the capacity of the electric power station and the energy quantity required for the facility to produce the products in each period.

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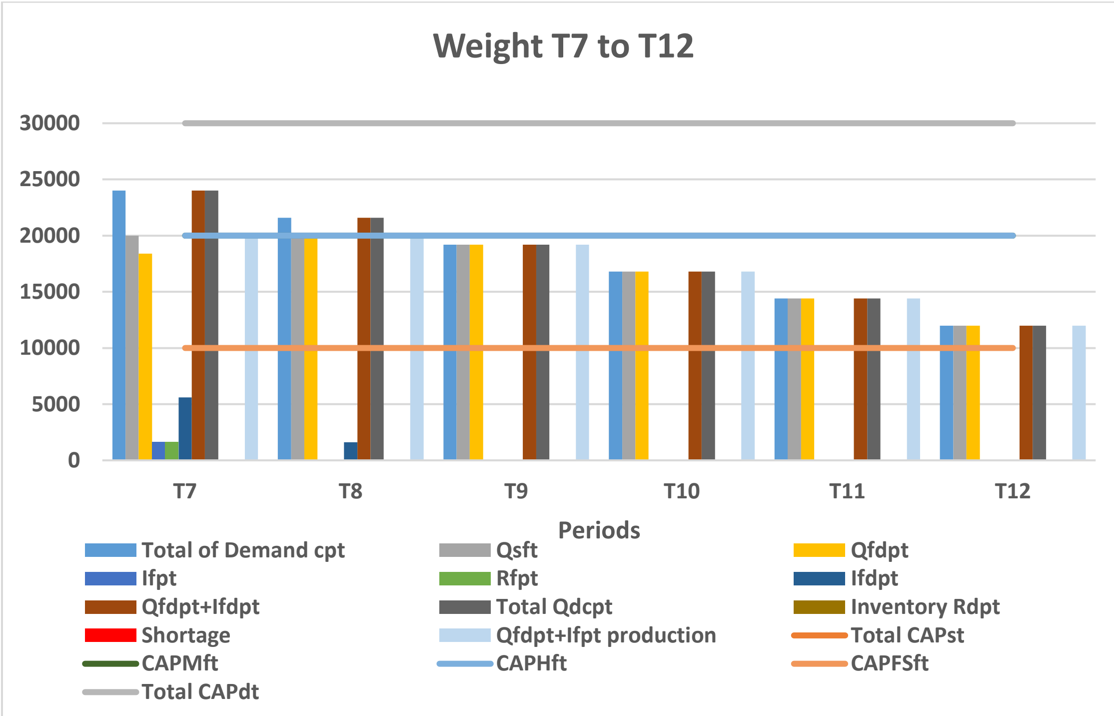

Figure 7 General flow of weights period 7 to 12 for everything related to the batches size in scenario 1.

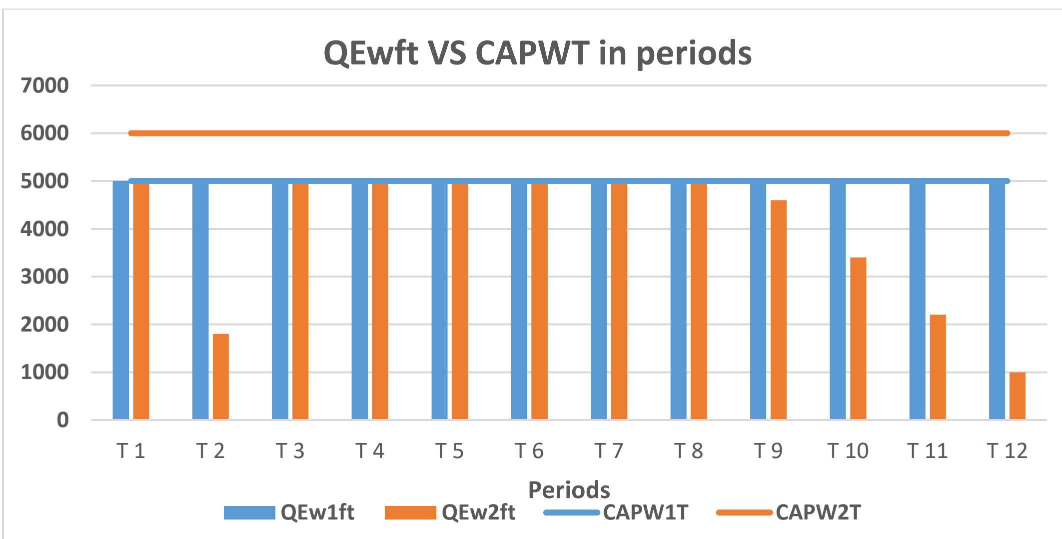

Figure 8 Relationship between the power stations' capacities and quantity of energy consumed in scenario 1.

It is evident from Figure 8 that:

- The electrical capacity of the first station was used by the facility to manufacture products.
- Most of the electrical capacity of the second station was consumed by the facility to produce products, except for certain periods (2, 9, 10, 11, and 12).

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- The total energy cost of the first station was higher than that of the second station, although it was lower for the consumption cost per kilowatt. The increase was because its entire electrical capacity was consumed.
- The decrease in production during periods (2, 9, 10, 11, and 12) led to a decrease in the amount of energy consumed by the factory during the same periods.

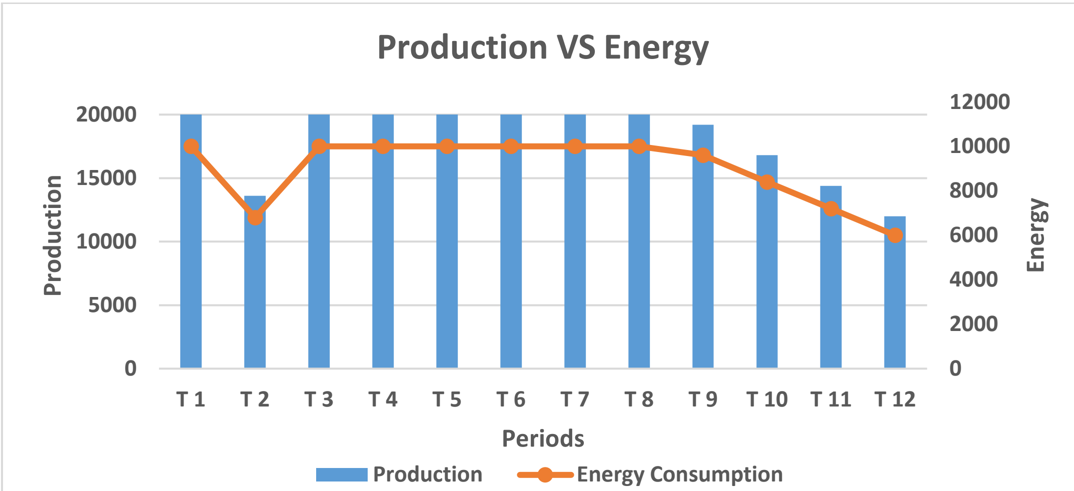

Figure 9 Relationship between the Production and Energy in scenario 1

It is clear from Figure 9 that the higher the production, the greater the energy consumed, and that the relationship between them is positive. Moreover, if the energy consumed increases, the cost price will increase, which will lead to higher costs in general and affect profits.

Scenario 2

The tables and graphics below show the results for the second Scenario. It shows the quantities transferred from one party to another, the quantities stored in the warehouses, the quantities of energy supplied to the factory, the costs that paid, profits, and other aspects.

Figure 10 shows the percentage of each type of cost compared with the total cost.

Figure 10 indicates that:

- Very high profits in comparison to the types of costs incurred.
- The cost of materials was the highest of all costs.
- The cost of manufacturing was very close to the cost of materials, which together constituted more than half of the considered costs.
- There was a certain cost shortage, which indicates that there is a shortage of products and that not all customers' needs were satisfied. Thus, the level of customer service was less than 100% for the third and fourth customers because the shortage accumulated to the end and the raw materials were used from the suppliers as the demand was high during the early periods.
- The energy incurred the lowest cost paid in this model, thereby indicating the success of the model in the energy economy.

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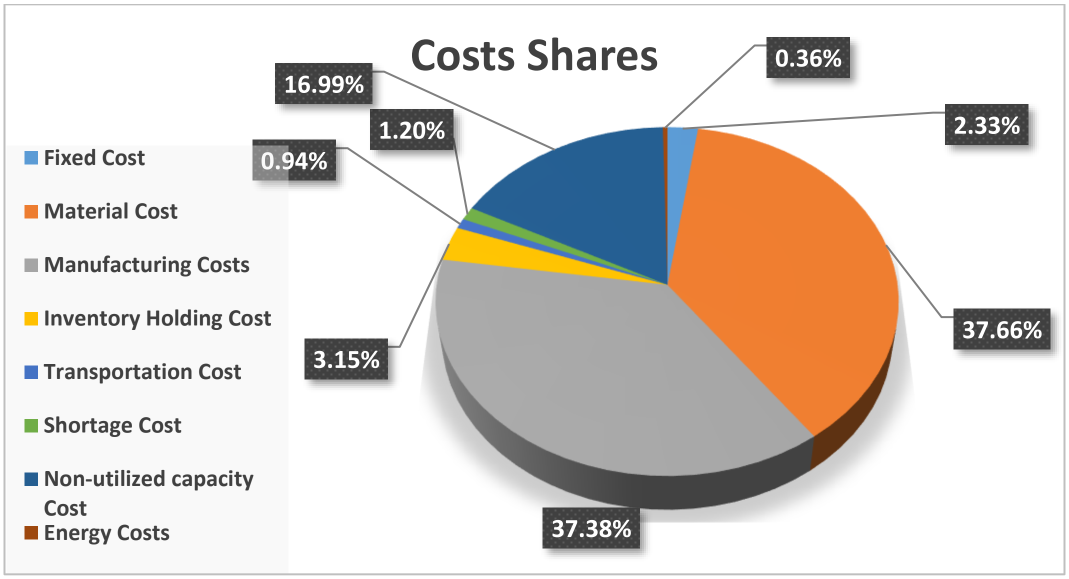

Figure 10 Costs Shares in scenario 2.

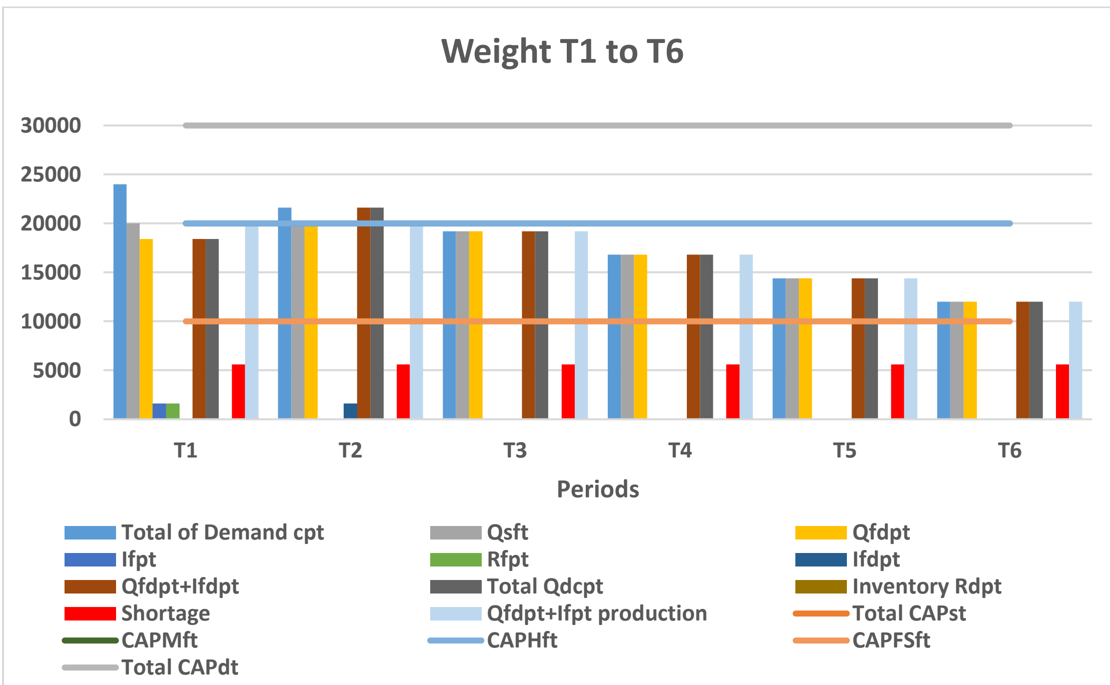

Figure 11 The general flow of weights period 1 to 6 for everything related to the batch size in scenario 2

From Figure 11, it is clear that:

- The demand and production decreased linearly.
- All the raw materials supplied by the suppliers were manufactured directly.
- The shortage of quantities was from the first period to the end.
- Certain products were stored in the factory warehouse in the first period only.
- No residual inventory in the distributor's store.

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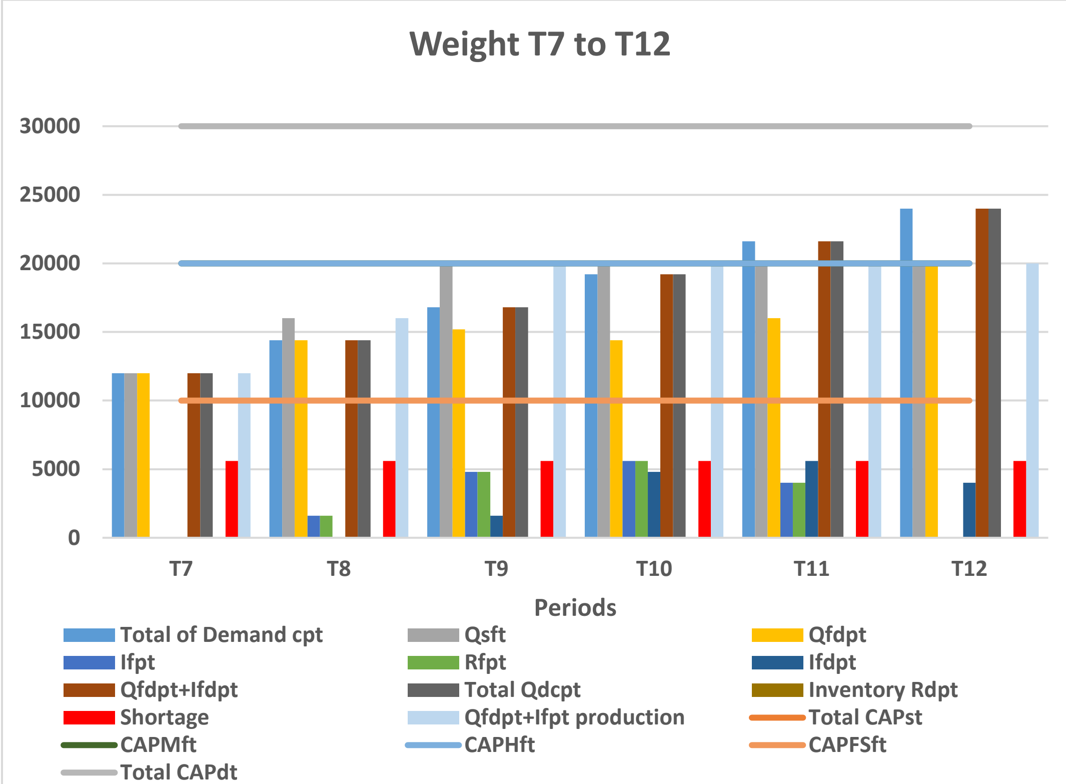

Figure 12 The general flow of weights period 7 to 12 for everything related to the batches size in scenario 2

From Figure 12, it is clear that:

- Both production and demand increased linearly.
- Only in periods 9,10,11, and 12, the production reached the facility's maximum manufacturing capacity.
- The shortage of quantities was from the first period to the end.
- Many products were stored in the factory warehouse.
- No products were residually stored in the distributor's warehouse.
- Owing to a shortage in certain quantities, all demands were not satisfied.

Figure 13 shows the relationship between the capacity of the electric power station and the energy quantity required for the facility to produce the products in each period.

It is evident from Figure that:

- The electrical capacity of the first station was used and completely consumed by the facility to manufacture the products.
- Most of the electrical capacity of the second station was consumed by the facility to produce products, except for certain periods (3, 4, 5, 6, 7, and 8), because the production process was reduced.
- The total energy cost of the first station was higher than that of the second station, although it was lower for the consumption cost per kilowatt. The increase was because its entire electrical capacity was consumed.
- The decrease in production during periods (3, 4, 5, 6, 7, and 8) led to a decrease in the amount of energy consumed by the factory during the same periods.

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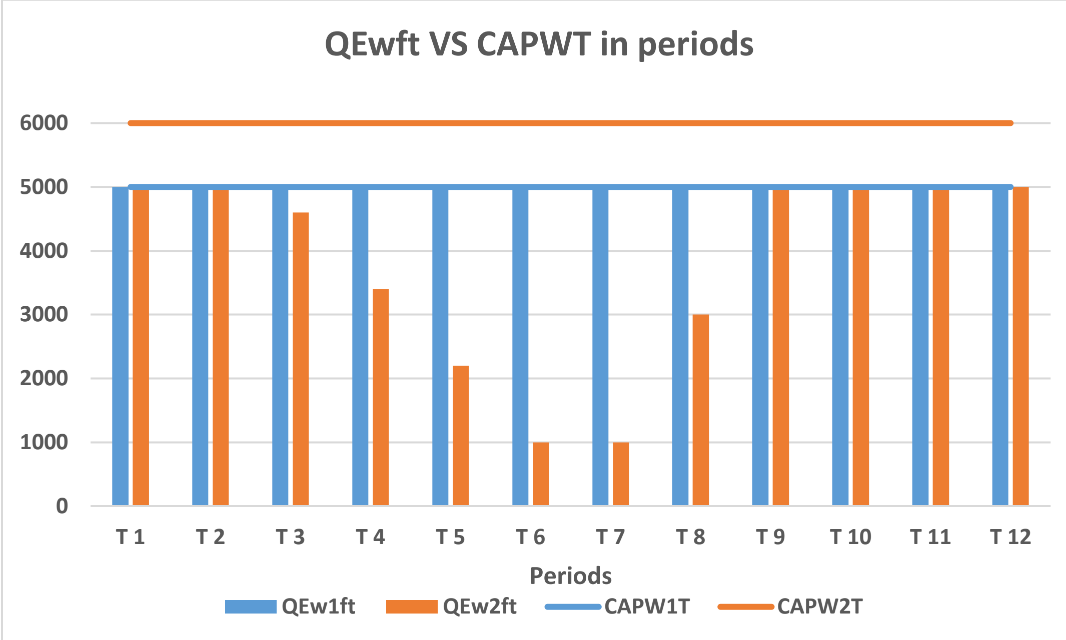

Figure 13 Relationship between the power stations' capacities and quantity of energy consumed in scenario 2.

It is clear from figure 14, that the higher the production, the greater the energy consumed, and that the relationship between them is positive. Moreover, if the energy consumed increases, the cost price will increase, which will lead to higher costs in general and affect profits.

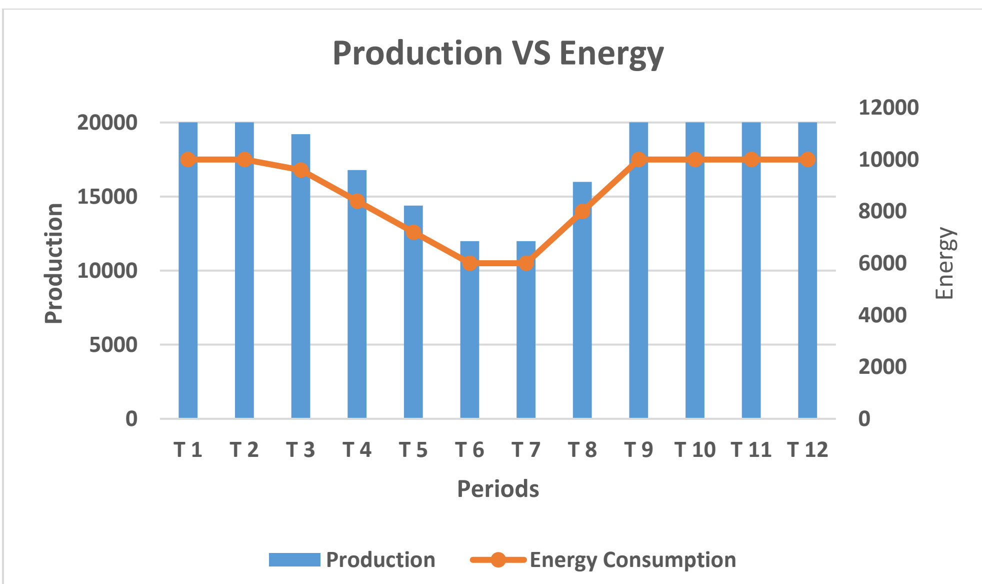

Figure 14 Relationship between the Production and Energy in scenario 2

4. CONCLUSION

The proposed model succeeded in achieving high profits while controlling the amount of energy consumed by the factory during manufacturing, as well as in solving production planning problems for many reasons, including:

- The percentage of profits in the two scenarios was more than 100%.
- Energy was the least expensive of all costs associated with production, and no energy was wasted.

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- The amount of energy consumed by the plant increased with an increase in production. Therefore, energy costs increased and decreased with a decrease in any of them.
- All the requirements of the four customers were satisfied in the first scenario, whereas certain shortages were observed in the second scenario, particularly among the third and fourth customers.
- Only one supplier was used in both scenarios. To use the others, there may be a need to increase raw materials and demand or reduce the supplier's capacity because it was very high.
- All warehouses at the facility and distributors were used in the first scenario, and all distributors distributed the required quantities, which confirmed the efficiency of the model.
- The material and manufacturing costs in both scenarios constituted more than half of the costs paid.

FUTURE RECOMMENDATIONS

This model may be improved in the future through the following ideas:

- Increasing the number of factories, distributors, and objectives.
- The values of electricity consumed by suppliers and distributors are calculated and incorporated into the accounts, constraints, and objectives, and connecting power stations to them. This will render the model more comprehensive and generalised.
- Finding cheaper manufacturing materials to increase profits and control the cost of manufacturing materials and workmanship, provided product quality is not compromised.
- Creating a method of delivering products to customers using electric trucks, including the cost of charging them with electricity in the costs paid, and connecting them to customer delivery operations.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. K. Khalili-Damghani and A. Shahrokh, "Solving a new multi-period multi-objective multi-product aggregate production planning problem using fuzzy goal programming," Industrial Engineering and Management Systems, vol. 13, no. 4, pp. 369–382, 2014, doi: 10.7232/iems .2014.13.4.369.
2. L. F. Liu and X. F. Yang, "Multi-objective Aggregate Production Planning for Multiple Products: A Local Search-Based Genetic Algorithm Optimization Approach," International Journal of Computational Intelligence Systems, vol. 14, no. 1, 2021, doi: 10.1007/s44196-021-00012-1.
3. M. S. Al-Ashhab, "An Optimization Model for Multi-Period Multi- Product Multi-Objective Production Planning," International Journal of Engineering & Technology IJET-IJENS, vol. 16, no. 01, pp. 43–56, 2016.
4. M. S. Al-Ashhab, T. Attia, and S. M. Munshi, "Multi-Objective Production Planning Using Lexicographic Procedure," American Journal of Operations Research, vol. 7, no. 03, p. 174, 2017, [Online]. Available: https://www.scirp.org/html/2-1040550_76055.htm?pagespeed=noscript.
5. M. S. Alashhab and E. A. Mlybari, "Developing a robust green supply chain planning optimization model considering potential risks," International Journal, vol. 19, no. 73, pp. 208–215, 2020.
6. M. K. Ghorabaee, M. Amiri, L. Olfat, and S. M. A. K. Firouzabadi, "Designing a multi-product multi-period supply chain network with reverse logistics and multiple objectives under uncertainty," Technological and Economic

Development of Economy, vol. 23, no. 3, pp. 520–548, 2017, doi: 10.3846/20294913.2017.1312630.

7. B. Ostadi, D. Moazzami, and K. Rezaie, "A non-linear programming model for optimization of the electrical energy consumption in typical factory," Applied Mathematics and Computation, vol. 187, no. 2, pp. 944–950, 2007, doi: 10.1016/j.amc.2006.09.138.
8. C. Cambero and T. Sowlati, "Incorporating social benefits in multi-objective optimization of forest-based bioenergy and biofuel supply chains," Applied Energy, vol. 178, pp. 721–735, 2016, doi: 10.1016/j.apenergy.2016.06.079.
9. R. H. Huang, T. H. Yu, and C. Y. Lee, "Rolling Supply Chain Scheduling considering Suppliers, Production, and Delivery Lot-Size," Mathematical Problems in Engineering, vol. 2018, 2018, doi: 10.1155/2018/8601209.
10. A. Entezaminia, M. Heydari, and D. Rahmani, "A multi-objective model for multi-product multi-site aggregate production planning in a green supply chain: Considering collection and recycling centers," Journal of Manufacturing Systems, vol. 40, pp. 63–75, 2016, doi: 10.1016/j.jmsy.2016 .06.004.
11. Subramanian Pazhani, "Multi-period multi-product closed loop supply chain network design," www.sciencedirect.com, 2021.
12. S. Xu, W. Wu, Y. Yang, B. Wang, and X. Wang, "Stochastic Real-time Power Dispatch with Large-scale Wind Power Integration and its Analytical solution," 2019.
13. J. Wang, X. Wang, and M. Yu, "Multi-Period Multi-Product Supply Chain Network Design in the Competitive Environment," Mathematical Problems in Engineering, vol. 2020, 2020, doi: 10.1155/2020/8548150.
14. S. Gupta, A. Haq, I. Ali, and B. Sarkar, "Significance of multi-objective optimization in logistics problem for multi-product supply chain network under the intuitionistic fuzzy environment," Complex & Intelligent Systems, vol. 7, no. 4, pp. 2119–2139, 2021, doi: 10.1007/s40747-021-00326-9.
15. B. V Chowdary and J. Slomp, "Production Planning under Dynamic Product Environment : A Multi-objective Goal Programming Approach," 2002.
16. S. C. Cerda-Flores, A. A. Rojas-Punzo, and F. Nápoles-Rivera, "Applications of Multi-Objective Optimization to Industrial Processes: A Literature Review," Processes, vol. 10, no. 1. MDPI, 2022, doi: 10.3390/pr10010133.
17. P. K. Dey, W. Cheffi, and B. Nunes, "Erratum: Green supply chain performance measurement using the analytic hierarchy process: A comparative analysis of manufacturing organisations (Production Planning and Control (2014) 25:9 doi: 10.1080/09537287.2012.751186)," Production Planning and Control, vol. 25, no. 9, 2014, doi: 10.1080/09537287.2012 .751186.
18. E. A. M. M. S. Al-Ashhab, "A tactical multi-objective multi-product green supply chain planning optimization model," International Journal of Engineering & Technology, vol. 7, no. 4, pp. 6192–6199, 2018, doi: 10.14419/ijet.v7i4.23127.
19. M. El Ashhab, "An Optimization Model for Multi-period Multi-Product Multi-objective Production Planning Supply Chain Network Design Optimization Model for Multi-period Multi-product under Uncertainty View project A stochastic model for forward-reverse logistics network." 2016, [Online]. Available: https://www.researchgate.net/publication/299345793.