CHEMICAL ENGINEERING TRANSACTIONS

VOL. 52, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Peng-Yen Liew, Jun-Yow Yong, Jiří Jaromír Klemeš, Hon Loong Lam

ISBN 978-88-95608-42-6; **ISSN** 2283-9216

DOI: 10.3303/CET1652179

Supply Chain Design Network Model for Biofuel and Petrochemicals from Biowaste

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Supply Chain (SC) is the effective coordination and integration of all activities performed by several business lines and their infrastructures; such as raw material suppliers, manufacturers, distributors and retailers till delivering the products to the customer.

The supply chain facilities location is an important issue which is needed to be solved as it is one of the important pillars in the supply chain design model. Therefore, it is critical for supply chain managing teams and designers to adopt the latest scientific and most effective methods to locate a facility by carrying different scenarios and trade-offs assessment, the used tools are only a decision supporting tools.

This paper concentrates on the development status of a decision-support tool for solving supply chain design including location problem of various facilities, using the MILP mixed integer linear problem solving programming model by constructing a generic analytical algorithm to solve this problem. EXECL SOLVER TOOL, MATLAB SOFTWARE with a GUI (graphical user input interface) programmed by the C# (C SHARP) programming software are used. In the MILP programming model iterative algorithm methods are used, where every iteration would generate a whole different new set of solutions to match some constrains, conditions and service levels added by the programmer. The first solution only matches some previous added criteria, resulting in a new set of solutions in the iteration, until finally an optimal solution rises under dynamic environment.

In this paper, a typical three layers medium term planning mixed integer linear Programme MILP model for supply chain design is presented and applied for chemicals and biofuel production from rice straw biomass. These three stages are commonly: raw materials collecting areas, distribution center and manufacturing plant locations. With the aid of ASPEN HYSYS simulation software and CAPCOST TOOL, Economic feasibility studies are done for designing supply chain design model. Different scenarios are examined which is a good way to price out potential solutions.

1. Introduction

Both The project owners and the government concentrates at the beginning of any project on the facility location problems from both macro and micro prospective, as it will affect production processes, efficiency, quality and cost, these all are going to affect the income of the marketing options for products as well as the project annual cash flow and economic market position. Factors affecting facility location choice are divided into the economic factors and non-economic cost factors. Economic factors can be quantified, such as raw materials cost, transportation cost, manufacturing cost, labour cost, utilities cost, land cost, storage costs and distribution centers cost. Non-economic cost factors, such as the region's cultural, public acceptance of such a project, regional development, political factors and environmental effects. This paper predetermines service levels to solve complex composite facility location problems as a part of the supply chain design model to reach the optimum solution. The supply chain facility location problem is summed up by many specific examples, such as plant location, distribution center locations, raw material location, all the economic micro and macro cost disintegration of all these activities, etc.

Please cite this article as: Emara I. A., Gadalla M. A., Ashour F. H., 2016, Supply chain design network model for biofuel and petrochemicals from biowaste, Chemical Engineering Transactions, 52, 1069-1074 DOI:10.3303/CET1652179

2. Problem Statement

Egypt is the largest rice producer in the Middle East region, Egypt export rice to different countries around the world about 60 countries, as it has competitive prices. Egyptian farms are producing one of the world's highest rice yields. The average Egyptian Rice farm yield in 2006 – 2007 was 3.5 t per Fadden. Rice consumption per person in Egypt in 2006 was 45 kg/y, the total local consumption was nearly 4 MMt/y and the total amount available for export is 2 MMt/y. Egypt produce 6.11 MMt rice/y, with rice straw to grain ratio = 0.65, therefore, a total production of 4 MMt rice straw/y. The main problem is Rice straw open-field insitu burning which is one of the major source of air pollutants, producing emissions such as carbon dioxide (CO_2), carbon monoxide (CO), traces of methane (CH_4), un-burnt carbon, nitrogen oxide (N_2O) and a less amount of sulphur dioxide (SO_2).

Great accuracy in estimating the air pollutant emissions including GHG emissions from rice straw open-field in situ burning is needed, to be able to calculate the value of environmental impact from rice straw burning and compare it with the other rice straw management options, (Gadde et al., 2009).

In order to compare, a Cost-Effectiveness Analysis (CEA) is done which is a systematic method of finding the lowest-cost option among a set of different combinations of policy and cost disintegration measures to reach a target (Povellato et al., 2007). CEA is an economic tool that considers the monetary costs of alternatives to perform a specific task.

In the studied case, a CEA was performed to calculate the total cost of the social and environmental GHG emissions and the cost of constructing a plant with all its cost items to choose the optimum capacity of rice straw from the total amount of Egypt production.

3. Solution Approach

A comprehensive feasibility study using Budget cost estimate in the planning project phase which is of (±15%) of the project implementation cost. ASPEN HYSYS simulation tool is integrated with the aid of CAPCOST costing tool to carry a material flow and cash flow analysis for a plant producing biofuel and petrochemicals from rice straw after gasification process. The target is to optimize the combination of raw materials collecting areas, distribution center and manufacturing plant locations. EXECL SOLVER TOOL, MATLAB SOFTWARE with a GUI (graphical user input interface) programmed by the C# (C SHARP) programming software are used to design MILP mixed integer linear Problem program model for the three layered medium supply chain design with optimization iterative algorithm methods are used, where every iteration would generate a whole different new set of solutions to match some constrains, conditions and service levels added by the programmer.

4. Mathematical Model

The supply chain design is formulated as a multi-scenario mixed-integer linear problem MILP that considers the uncertainty associated with the coefficients of the objective function of the model (i.e. operating costs, raw materials prices, etc.).The model combines between decision variables and objective function subjected to some constrains with linking equations. Objective is to find optimum locations for supplying (a) Raw Materials, (b) Distribution centers and (c) Plant, from a list of candidate locations in order to minimize the total cost of transpiration and delivering between these three points to construct a network using (MILP).

a. Objective Function :

Total Cost (Z) = $\sum_i \sum_j C_{ij} X_{ij} + \sum_i f_i Y_i$ (D.C Fixed Cost) +Outbound O.B Transport + Inbound I.B Transport+ Manufacturing (Raw material cost) cost +D.C handling Cost.

b. Subjected to constrains :

$Z = \sum_j X_{ij} \leq S_i \quad \forall_i \in S$ (1)

$Z = \sum_i X_{ij} \geq D_j \quad \forall_j \in D$ (2)

$X_{ij} - M_{ij} Y_i \leq 0 \quad \forall\, i, j$ (3)

$\sum_i Y_i \geq P_{Min}$ (4)

$\sum_i Y_i \leq P_{Max}$ (5)

$X_{ij} \geq 0 \quad \forall\, i, j$

$Y_i = \{0,1\} \quad \forall\, i$

c. Decision variables
- X = amount.
- Y = binary variable for D.Cs whether to open or not.

d. Indices:
- Inbound: Raw material areas, Distribution centers (D.C) = i.
- Outbound: Distribution centers, Plant = j.

e. Input Data:
- S_i = Available raw material supply at primary location and D.C $\forall$ i ϵ S.
- D_j = Demand by D.C j from farm i, plant j from D.C i $\forall$ j ϵ D.
- C_{ij} = Total cost to serve D.C j from raw material location i, plant j from D.C i $\forall$ i, j.
- F_i = Fixed cost to open D.C i $\forall$ i ϵ S.
- P_{Min} = Minimum number of D.Cs allowed to open
- P_{Max} = Maximum number of D.Cs allowed to open.
- M = A big number, let equal the capacity at each D.C.

Objective is to minimize the total cost (Z), and then use it to calculate cost per unit weight for the rice straw raw material at the plant feed inlet after implementing the supply chain.

5. Case Study in Egypt

5.1 Optimum capacity choice

The base line calculations for the (a) Hysys simulation for the plant (b) Capcost economic calculations (c) Supply chain MILP model is calculated for the 40 % usage of the total available rice straw in Egypt. The assumption of dividing the FCIL (Fixed capital investments) on fixed equal instalments over the project life is used to make the calculations easier, but actually FCIL is paid in three instalments only elaborated in the economic feasibility study section. COL (Cost of Operating labour), CWC (Cost of working capital), CUT (Cost of utilities) are scaled up and down at various capacities using the capacity factor. Cs (Cost of supply chain) is calculated at various capacities using the predesigned MILP Supply chain model. FCIL is scaled up and down at various capacities using the sixth tenth rule. Rp (Revenue of product), is calculated by running the simulated Hysys plant simulation design at various capacities, the output data is imported in the Capcost tool.
After calculations Rice straw burning cost is found to be = 67 × 10^6 USD/ MMt Rice Straw. Costs fluctuate at different rice straw used percentage in the plant with only one decreasing cost which represents the environmental burning cost of rice straw, results shows that the minimum cost optimum capacity of the used percentage of rice straw is 60 % from the 4 MMt rice straw/y available in Egypt with a total amount of rice straw of 2.4 MMt rice straw/y.

5.2 Suggested locations

Farming areas of different rice straw available amounts as well as plant suggested locations are shown in capacities Figure 1 .A proposed model shown in Figure 2 having six farming areas, six distribution centers and four plant areas is designed containing possible 60 routes, trade-offs are carried using the supply chain model to choose the most economic routes using objective functions, decision variables, demand and constrains.

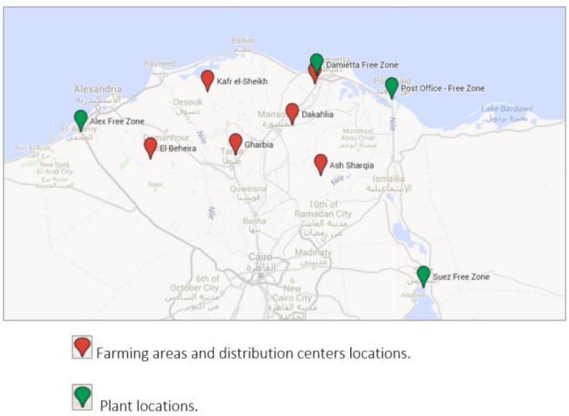


Figure 1: suggested locations

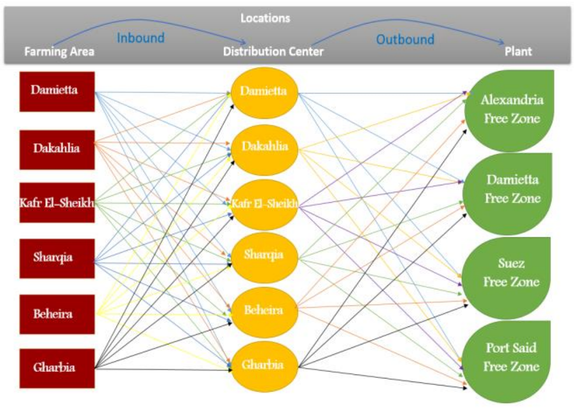


Figure 2: Supply chain possible route solutions

5.3 Methodology

All calculations are done by one click on the Run bottom in MATLAB, which in return call C# (C SHARP), after that press the Calculate bottom in the C# GUI Pop up window. Finally results will appear in the MATLAB command window. C# is used to take user inputs for the supply chain design, all the gaps should be filled by the user as shown in the Figure 3. After C# takes the 84 input from the user, a file of NOTEPAD ++ is created importing all the inputs into it, then the MATLAB software read these inputs from it, after that MATLAB apply its code to the inputs. The MATLAB code is of 248 line of mixed integer linear Problem MILP programming model for supply chain design correlating all the 84 input and the 48 variables with each other using the mathematical model mentioned in sections 4. C# (C sharp) Simulation Code of 362 line. In EXCEL Solver as an optimization tool is used. Variables are 42 quantity flow rates and 6 binary whether to open or close distribution centre variables.

Manufacturing var cost: The raw material cost. Maximum Straw (kg) – Capacity: The raw material capacity. OB Distance Matrix (km) From D.C To Plant, the desired plant location name. D.C Maximum capacity in (kg). Distribution Centers Variable Cost (USD). Distance IB (km) Between Distribution Centers (Rows) and Farms in Cities (Columns). QTY Demanded: Quantity demanded this to be used as Mij in the constrain equation: Xij - Mij Yi ≤ 0. D.C Fixed Cost (USD). Data Level of Service Constrains:

- Total Demand: amount demanded by the plant in (kg).
- IB Transp Cost USD/ (km.kg): Inbound transportation Cost.
- OB Transp Cost USD/ (km.kg): Outbound transportation Cost.
- Min DCs to Open: Minimum number of distribution centers to open.
- Max DCs to Open: Maximum number of distribution centers to open.

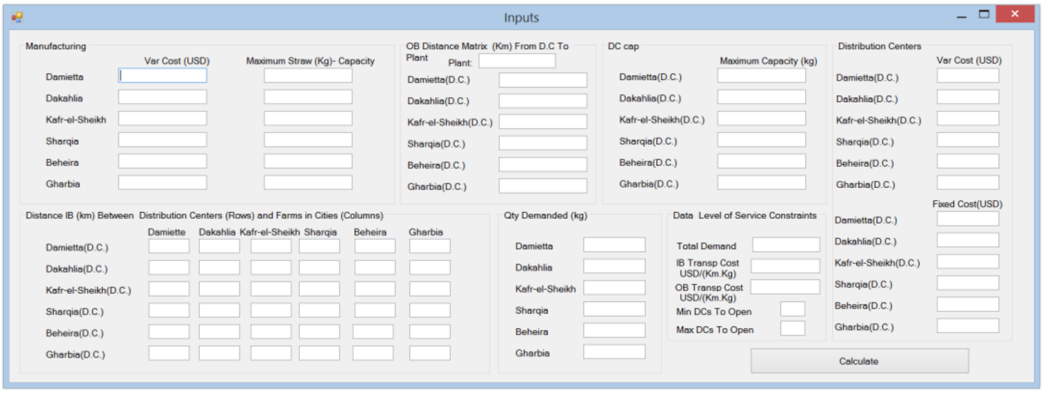


Figure 3: C# GUI for the Rice Straw Supply Chain Model.

5.4 Results and Discussions

The model is generated and calculations are done for the four plant locations in Alexandria, Damietta, Suez and Port-Said. Damietta is proved to be of minimum total annual cost (Z) for raw material of 91,533,308.79 USD, therefore cost per kg of rice straw = 91,533,308.79 USD / 2.4 MMt/yr = 0.0381 USD/kg. Figure 6 – 7 shows the results for both MATLAB and EXCEL outputs. MILP is solved using EXCEL SOLVER tool for double checking the results obtained from MATLAB and C# model. Excel method is also used in the Supply Chain Design course by Massachusetts Institute of Technology, MITx - CTL.SC2x. The model is somehow complicated, it is an optimization decision supporting tool connecting variables together in the least number of equations.

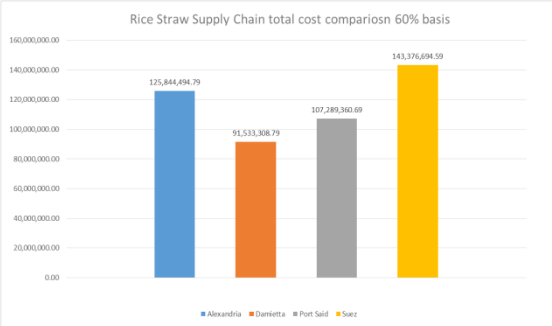


Figure 4: Total cost comparison 60 % Basis

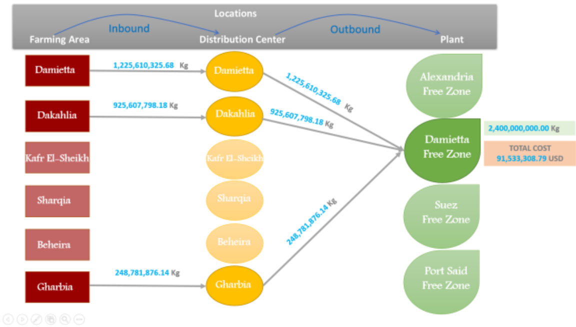
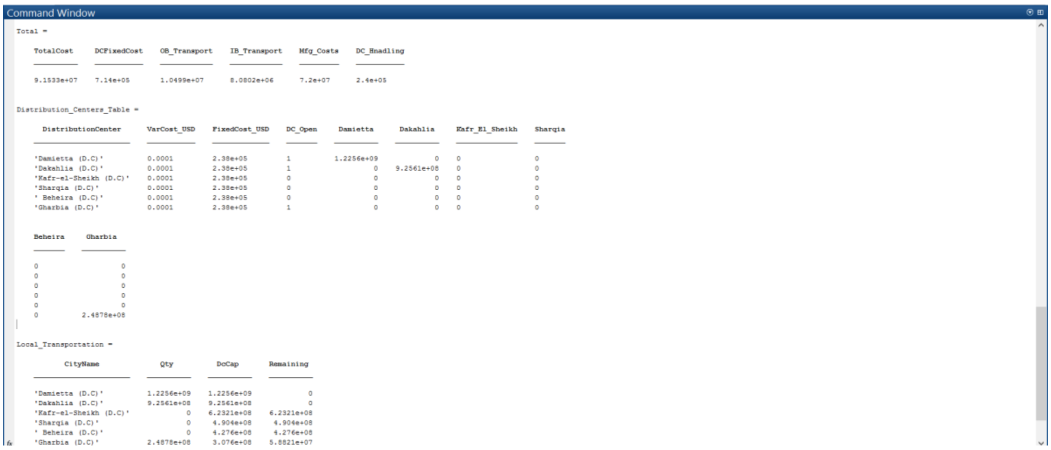
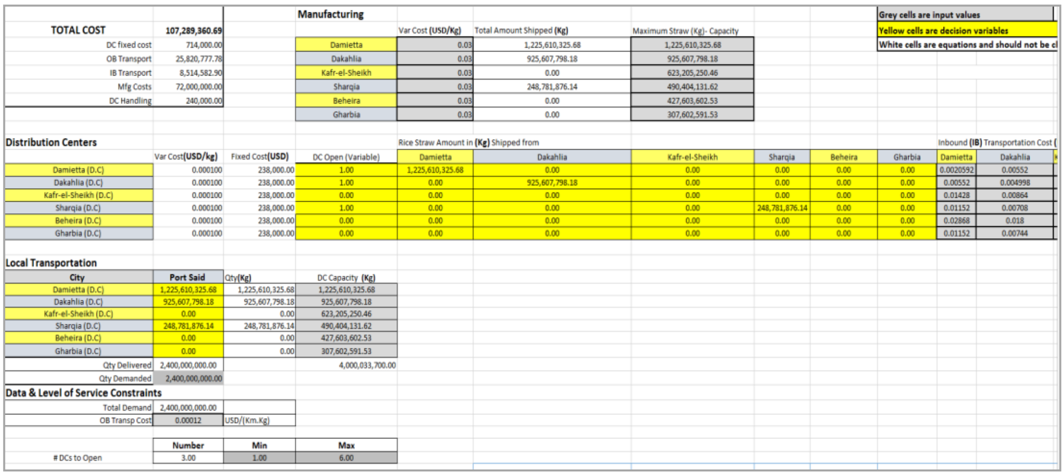


Figure 5: Supply chain results Damietta Plant 60 % basis



```
Command Window
Total =

    TotalCost    DCFixedCost    OB_Transport    IB_Transport    Mfg_Costs    DC_Hnadling
    _________    ___________    ____________    ____________    _________    ___________

    9.1533e+07   7.14e+05       1.0499e+07      8.0802e+06      7.2e+07      2.4e+05

Distribution_Centers_Table =

     DistributionCenter       VarCost_USD    FixedCost_USD    DC_Open    Damietta      Dakahlia      Kafr_El_Sheikh    Sharqia
    ______________________    ___________    _____________    _______    __________    __________    ______________    _______

    'Damietta (D.C)'          0.0001         2.38e+05         1          1.2256e+09             0    0                 0
    'Dakahlia (D.C)'          0.0001         2.38e+05         1                   0    9.2561e+08    0                 0
    'Kafr-el-Sheikh (D.C)'    0.0001         2.38e+05         0                   0             0    0                 0
    'Sharqia (D.C)'           0.0001         2.38e+05         0                   0             0    0                 0
    ' Beheira (D.C)'          0.0001         2.38e+05         0                   0             0    0                 0
    'Gharbia (D.C)'           0.0001         2.38e+05         1                   0             0    0                 0

    Beheira     Gharbia
    _______    __________

    0                   0
    0                   0
    0                   0
    0                   0
    0                   0
    0          2.4878e+08

Local_Transportation =

          CityName              Qty          DcCap       Remaining
    ______________________    __________    __________    __________

    'Damietta (D.C)'          1.2256e+09    1.2256e+09             0
    'Dakahlia (D.C)'          9.2561e+08    9.2561e+08             0
    'Kafr-el-Sheikh (D.C)'             0    6.2321e+08    6.2321e+08
    'Sharqia (D.C)'                    0     4.904e+08     4.904e+08
    ' Beheira (D.C)'                   0     4.276e+08     4.276e+08
    'Gharbia (D.C)'           2.4878e+08     3.076e+08    5.8821e+07
```

Figure 6: MATLAB Supply chain MILP solution for plant in Damietta 60 % basis



TOTAL COST	107,289,360.69
DC fixed cost	714,000.00
OB Transport	25,820,777.78
IB Transport	8,514,582.90
Mfg Costs	72,000,000.00
DC Handling	240,000.00

Manufacturing

	Var Cost (USD/Kg)	Total Amount Shipped (Kg)	Maximum Straw (Kg)- Capacity
Damietta	0.03	1,225,610,325.68	1,225,610,325.68
Dakahlia	0.03	925,607,798.18	925,607,798.18
Kafr-el-Sheikh	0.03	0.00	623,205,250.46
Sharqia	0.03	248,781,876.14	490,404,131.62
Beheira	0.03	0.00	427,603,602.53
Gharbia	0.03	0.00	307,602,591.53

Grey cells are input values
Yellow cells are decision variables
White cells are equations and should not be c

Distribution Centers

	Var Cost(USD/kg)	Fixed Cost(USD)	DC Open (Variable)	Rice Straw Amount in (Kg) Shipped from: Damietta	Dakahlia	Kafr-el-Sheikh	Sharqia	Beheira	Gharbia	Inbound (IB) Transportation Cost (: Damietta	Dakahlia
Damietta (D.C)	0.000100	238,000.00	1.00	1,225,610,325.68	0.00	0.00	0.00	0.00	0.00	0.0020592	0.00552
Dakahlia (D.C)	0.000100	238,000.00	1.00	0.00	925,607,798.18	0.00	0.00	0.00	0.00	0.00552	0.004998
Kafr-el-Sheikh (D.C)	0.000100	238,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01428	0.00864
Sharqia (D.C)	0.000100	238,000.00	1.00	0.00	0.00	0.00	248,781,876.14	0.00	0.00	0.01152	0.00708
Beheira (D.C)	0.000100	238,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02868	0.018
Gharbia (D.C)	0.000100	238,000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01152	0.00744

Local Transportation

City	Port Said	Qty(Kg)	DC Capacity (Kg)
Damietta (D.C)	1,225,610,325.68	1,225,610,325.68	1,225,610,325.68
Dakahlia (D.C)	925,607,798.18	925,607,798.18	925,607,798.18
Kafr-el-Sheikh (D.C)	0.00	0.00	623,205,250.46
Sharqia (D.C)	248,781,876.14	248,781,876.14	490,404,131.62
Beheira (D.C)	0.00	0.00	427,603,602.53
Gharbia (D.C)	0.00	0.00	307,602,591.53
Qty Delivered	2,400,000,000.00		4,000,033,700.00
Qty Demanded	2,400,000,000.00		

Data & Level of Service Constraints

Total Demand	2,400,000,000.00	
OB Transp Cost	0.00012	USD/(Km.Kg)

	Number	Min	Max
# DCs to Open	3.00	1.00	6.00

Figure 7: EXCEL Supply chain MILP model part for plant in Port Said 60 % basis

CAPCOST Cash flow analysis shown in Figure 8 is based on 3 years construction period and plant life time of 20 years. Plant is producing methanol, nitrogen, hydrogen, carbon dioxide and dimethyl-ether with annual revenue of 536,504759 USD. Fixed capital investment cost of 746,200,000 USD. Rice straw annual cost is 91,533,308.79 USD. Resulting in a payback period of 5.2 years based on discounted cash flow of interest rate 10 % and income tax rate 20 %.

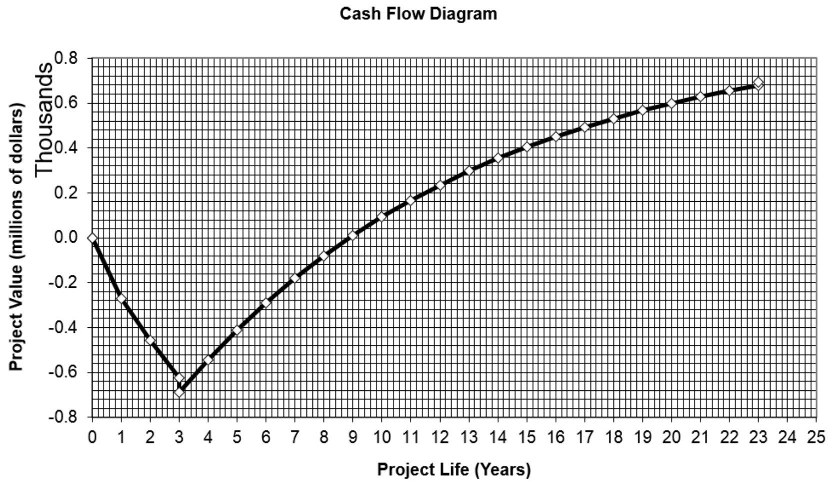


Figure 8: Cash flow diagram rice straw plant Egypt case after supply chain model integration 60% basis

6. Conclusions

The potential of renewable energy sources in Egypt is very great but it needs concern from both government and investors. Rice straw is a strategic raw material if used for producing chemicals and biofuels such as methanol rather than burning it.

Each supply chain model has its own parameters, the goal is to link all parameters with each other in an effective way. In the two mentioned case studies, raw materials, various transportation lines nodes and its transportation cost is of large running and capital cost share compared to the whole project, from this point the supply chain designed is so sensitive.

Supply chain network design is only a decision supporting tool that can be solved by many programming languages, in this thesis EXECL SOLVER TOOL, MATLAB SOFTWARE and C# (C Sharp) programming language was used to create the MILP model. The decision supporting tool should be used with other tools like ASPEN HYSYS, CAPCOST TOOL to be able construct a practical strategic decision and an economic feasibility study.

This paper presented a mixed integer linear programmed mathematical practical problem solution and approach to analyse the feasibility, profitability, cost effectiveness, industrial applications and operation for a sustainable development supply chain network design projects.

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