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Energy Management in Cogeneration System of Sugar Industry Using System Dynamics Modeling

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ABSTRACT

Energy management is the judicious and effective use of energy to maximize profits and enhance competitive positions through organizational measures and optimization of energy efficiency in the process. India faces a peak electric generating shortage of over 20% and an energy shortage of 12%. India is the world's largest producer of sugar, with over 430 sugar mills producing an estimated 12 millions tons of sugar annually. The rapidly changing markets for sugar and energy provide an excellent opportunity to develop innovative methods to optimize cogenerated power from the sugar plants that can reduce the energy shortage faced by the country. An effort is made in this article to employ a system dynamics methodology to model a cogeneration system in the sugar industry. Simulation of a cogeneration system by system dynamics software is carried out to get different data used for the determination of energy management policy. It is shown that energy management activities can be improved through system dynamics modeling. The various applications point out the advantages of "system dynamics," particularly in energy management, and assisting decision making procedures in the management level.

Key Words: Energy management, sugar industry, cogeneration, system dynamics.

INTRODUCTION

Energy management is "the judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions" [1]. Energy management in any industry is desirable for financial, social and environmental reasons. The financial reasons focus on the profitability and potential growth of the enterprises, whereas the social and environmental reasons focus on the benefits that the enterprises, their workers and the society gets from an energy management program. The role of energy management has greatly expanded in industries. Major industries are contracting with energy service providers to implement energy management practices to improve efficiency [2].

The sugar industry is an energy intensive industry and by its inherent nature can generate surplus energy in contrast to the other industries, which are only consumers of energy. With liberalization and increased competition, the generation and selling of excess power to the electricity board, offers an excellent source of revenue generation to the sugar plants. This is referred to as commercial cogeneration and has been only marginally tapped in India. In this context, the saving of energy (steam and power) in a sugar plant becomes very important as "One unit saved is one unit sold ." The best method to achieve this is to incorporate energy management and efficiency aspects in a sugar industry [3], [4].

"System dynamics" is a modeling concept for dynamic systems, which has been developed by J.W. Forrester at the Massachusetts Institute of Technology (MIT) in Cambridge. "System dynamics" is a method that mutually links theories, procedures and philosophies that are necessary for analyzing the behavior of complex feedback systems encountered in various fields of economics, environmental science, corporate management, medicine or technology. It is based on cybernetic knowledge and utilizes, in addition to the approaches of system thinking, a numeric simulation to determine the behavior of non-linear systems [5]. Irrespective of the particular problem analyzed with system dynamics, an understanding of the basic system structure (system elements, feedback relationships...) is of paramount importance. System dynamics assumes that the structure of a system determines its behavior. The systems are described and calculated with the help of stock-and-flow diagrams. Simulation models can be developed that are capable of calculating aspects of future energy supply systems with computer support. Processes can be analyzed with system dynamics in structured and inter-disciplinary system orientated manner [6], [7].

In this article, the application of system dynamics as an effective management tool to resolve the complex dynamic issues of sugar industry energy management is discussed. System dynamics approach is a loop to check the behavior of a system over time. The inputs used to build a system dynamics model can be the basic performance parameters for energy management in an enterprise. Considering sugar industry as a system in whole, modeling such a system by system dynamics approach is an innovative task. STELLA software is used to simulate the system behavior. This software simulates the system model with a system dynamics approach. The system dynamics based model is built to develop policies to help energy management in cogeneration. Results show that the investigated policy options are cost-effective. In the following discussion, all descriptions and representations refer to the modeling and simulation software STELLA [8].

METHODOLOGY

In sugar factories when cane is processed, the cane stalks are shredded and crushed to extract the cane juice. The fibrous outer residue is known as bagasse, is sent to the boiler to produce steam and electricity for use in the industry as well as export. Any sugar industry designed and constructed today would be at least efficient enough to cover its own energy needs. With the availability of advanced cogeneration technologies, sugar factories today can harness the on site bagasse resource to go beyond meeting their own energy requirements and produce surplus electricity for sale to the state/national grid or directly to other electricity users. [9], [10].

Figure 1 shows the methodology for the application of system dynamics to energy management in the sugar industry. In the present study, only the cogeneration system in the sugar industry is considered for system dynamics modeling. In the sugar industry, the cogeneration plant, which produces power for in-house utility and out sources energy from the plant, is of paramount importance. System dynamics modeling can be used in the cogeneration plant so that optimum energy output can be obtained.

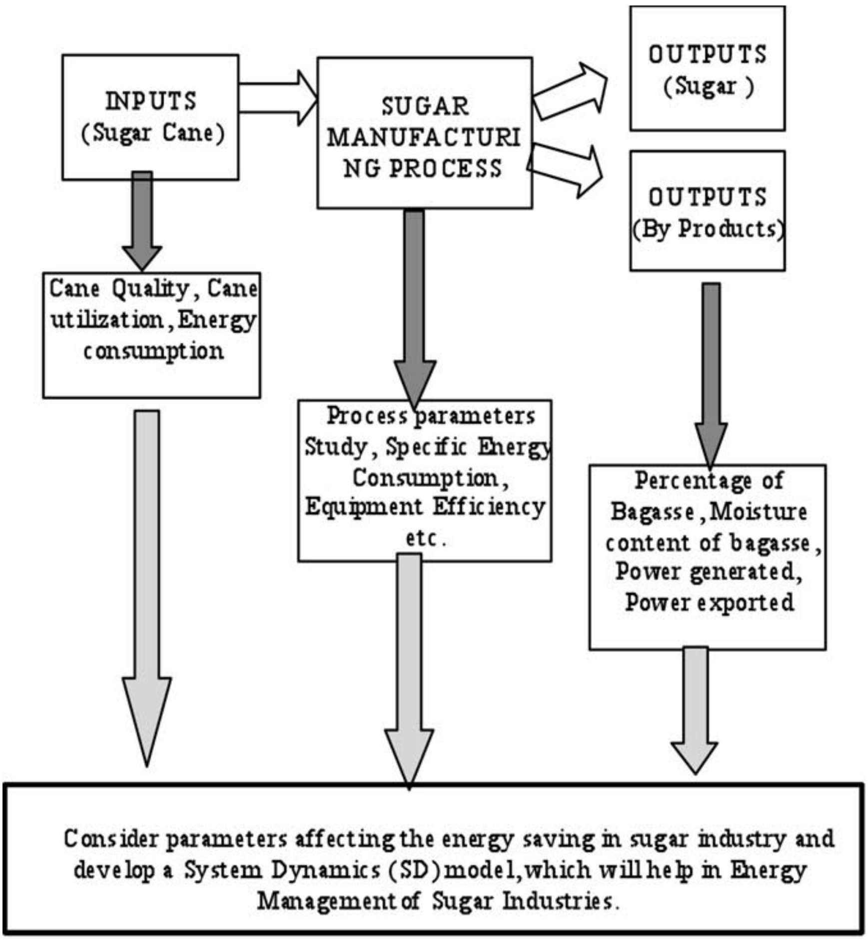

Figure 1. Applying System Dynamic Modeling to Energy Management in the Sugar Industry

The basic building block of system dynamics is a **stock or level**, which is used to represent anything that accumulates. The second building block is **flow or rate**, which is used to represent the activities that will change the magnitude of stock in a system. The third one is called **connector** to transmit information and inputs that are used to regulate the flows. The last building block is the **converter**, which contains an equation to generate an output value for each time period and often take information and transform it for use by another variable in the model. They are also handy for storing constant values.

SYSTEM DYNAMICS MODEL DEVELOPMENT FOR ENERGY MANAGEMENT IN COGENERATION

Basically, to model a system in system dynamics, a system must be subdivided in such a way that the subdivided elements must be independent of other elements of the subdivided system. After knowing all the independent elements, a model can be developed. These independent elements influence the behavior of the system in their own way. A sugar manufacturing system can be subdivided by the number of processes like milling, juice heating, evaporation, crystallization, cogeneration, etc. Each process is considered a subsystem for energy consumption. Each subsystem, in turn, can be subdivided until independent elements are obtained.

Cogeneration, as shown in the Figure 2, can be considered as one of the subsystems in the sugar manufacturing process.

It is found from the industries visited that a well-designed and operated cogeneration scheme will always provide better energy efficiency than a conventional plant, leading to both energy and cost savings. Because a single fuel is used to generate heat and electricity, cost savings are dependent on the price differential between the primary energy fuel and the purchased electricity from an external utility that the scheme displaces. However, although the profitability of cogeneration generally results from its cheap electricity, its success depends on using recovered heat productively, so the prime criterion is a suitable heat requirement. It is found from the study that cogeneration is likely to be suitable where there is a fairly constant demand for heat throughout the year.

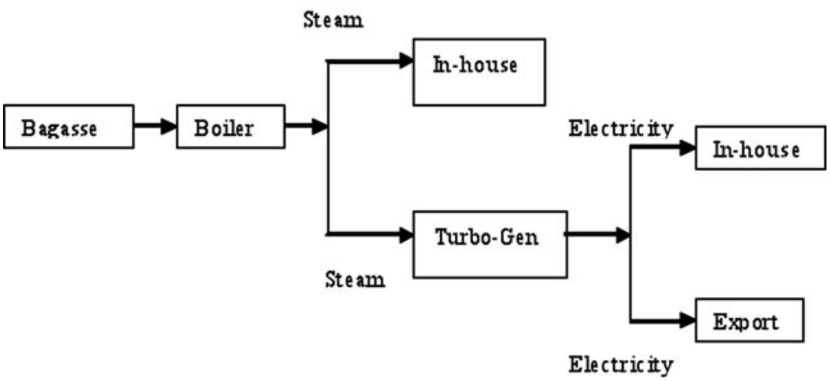

Figure 2. Cogeneration in the Sugar Industry

Elements of Cogeneration System

The list of subsystems and elements of these subsystems in cogeneration system are shown in the Table 1.

Table 1. Subsystems and Elements of a Cogeneration System

Sr. No.	Sub-subsystem	Independent Elements
1	Bagasse	Water content, calorific value, bagasse inventory
2	Boiler (amount of steam generated)	Boiler pressure, Rankine cycle efficiency, steam-to-fuel ratio, specific steam consumption
3	Turbo-generator	Inlet steam temperature, mechanical efficiency, alternator efficiency
4	In-house	In-house steam usage, in-house electricity usage
5	Export	Export contracts

Relation between elements and their influence:

Baggasse →	+	boiler utilization
Baggasse →	–	baggasse inventory
Cane crushed →	+	direct feed
Boiler capacity →	+	boiler utilization
Boiler utilization →	+	power generation
Baggasse →	–	purchase
Boiler capacity →	–	purchase
Baggasse inventory →	+	inventory cost
Export →	+	effective in-house
Export →	–	sold price
Sold price →	+	profit
Turbine efficiency →	+	power generation
Tech cost boiler →	+	cost
Purchase cost →	+	cost

[Note: + ve shows increasing effect; – ve shows decreasing effect]

The cogeneration system established here only contains the elements that influence the energy aspects in a sugar industry. Other elements that do not contribute towards energy in sugar industry are not considered. The cogeneration subsystem is divided into five individual sub-subsystems. Again these sub-subsystems have independent elements that will influence the behavior of individual systems. From Table 1 and the influencing elements, casual loop diagrams for each subsystem are drawn with detailed rate of influence. Causal loop diagrams are visual representations of the cause-and-effect relationships among elements of a system formulating structures of feedback loops. They represent an overall view of causal structure of a system. They are used in conceptualizing real life problems, in developing the model equations, in exploring the results of a simulation run, in designing new policies, etc.

System Dynamics Loop for Bagasse

Figure 3 illustrates the casual loop diagram for the bagasse subsystem.

Content of Water

Generally there will be 40-50% of moisture content present in bagasse after crushing. This bagasse is burnt as a fuel to raise the temperature of steam in the boiler, and good quality bagasse is a bagasse with lower moisture content. Moisture content reduces bagasse quality and therefore according to system dynamics it is taken as –ve.

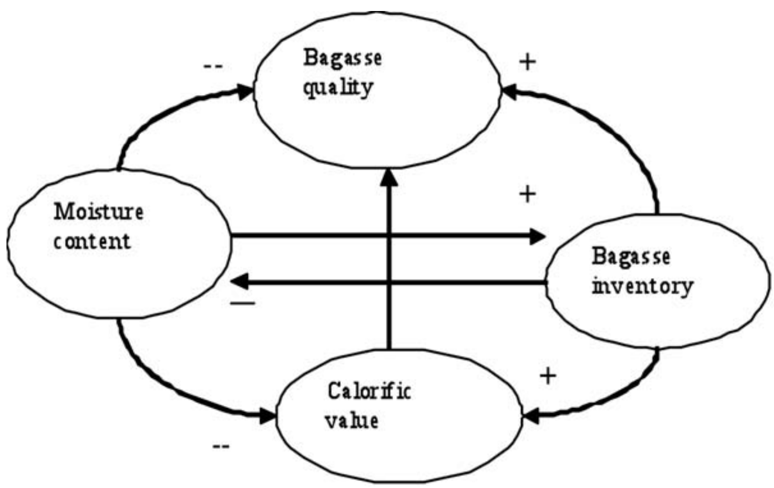

Figure 3. Casual Loop Diagram for the Bagasse Subsystem.

Calorific Value

A good bagasse always has high calorific value. Hence, it is taken as +ve.

Bagasse Inventory

Keeping bagasse in the sunlight or in store, the moisture content reduces. Therefore, bagasse quality improves and hence it is taken as +ve.

System Dynamic Loop for Boiler and In-house

Figure 4 illustrates the casual loop diagram for the boiler and in-house. Increase in boiler pressure results in a higher efficiency (η) but reduces bagasse quality; therefore, it is taken as negative. Steam generated in the boiler is sent to steam power plant where it is expanded up to certain pressure. Steam leaving from the power plant is fed to a condenser where steam is converted into water, which is returned to the boiler through a feed pump. Steam generated is used in-house and for electrical power generation for operating electrical equipment in the plant. Specific steam consumption refers to steam consumption per hour per unit power. When this is defined with respect to indicated horsepower (IHP), then it is called specific steam consumption on an IHP basis and when it is defined with respect to brake horsepower (BHP), then it is called specific fuel consumption on a BHP basis. Rankine efficiency

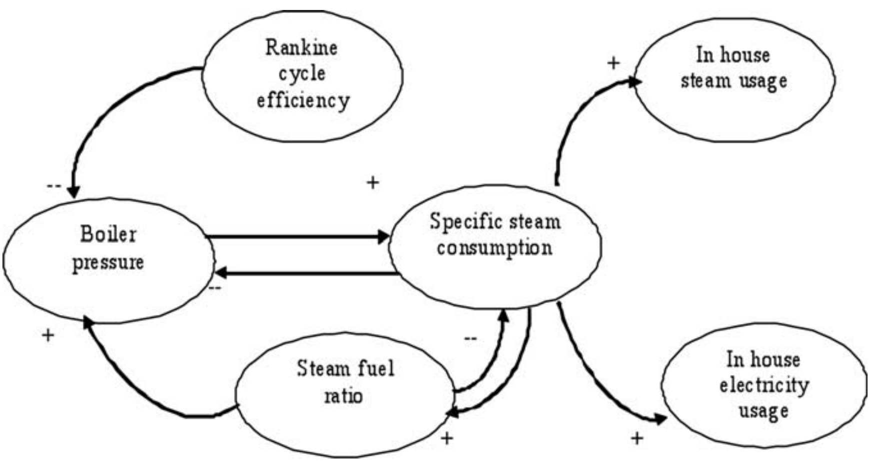

Figure 4. Casual Loop Diagram for Boiler and In-house

is given by the ratio of Rankine work available from the power plant to the energy supplied to steam power plant. Ratio of thermal efficiency to Rankin efficiency is known as relative efficiency.

System Dynamic Loop for Turbo-generator

Figure 5 illustrates the casual loop diagram for the turbo-generator. Thermal efficiency is the ratio of work done to the energy supplied to the steam power plant. Thermal efficiency may also be defined as the ratio of work done on a brake power basis to energy supplied to steam power plant. Mechanical efficiency of the power plant is given by the ratio of brake horsepower to indicated horsepower. Power available from the output shaft is less than the power developed inside the power plant as a result of frictional losses. Alternative efficiency is the actual power available from the alternator to power supplied from steam power plant. Overall efficiency of the plant is the product of mechanical efficiency and alternator efficiency.

System Dynamics Loop for Export

Figure 6 illustrates the casual loop diagram for export. After constructing the casual loop diagram for all subsystems of a cogeneration plant, a computer simulation model is built. During construction of computer simulation model, influencing rates of the above elements are taken as stocks and flows. The computer simulation shows the graphical

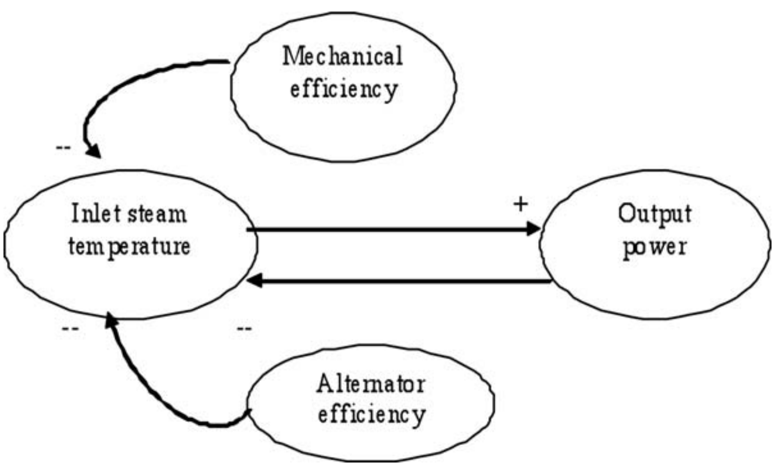

Figure 5. Casual Loop Diagram for the Turbo-generator

representation of the system behavior over a prescribed time. Initially some values of elements and rates are input to model simulation. By varying these initial inputs, different behavior of the system can be seen.

In this study with system dynamics, a sugar industry is simulated with respect to energy exchanges. The simulation shows the dynamic behavior of the energy situation in the sugar industry. Through variation of the independent elements for the input to the system model, a different situation may be created. By analyzing these situations, an energy management policy is developed.

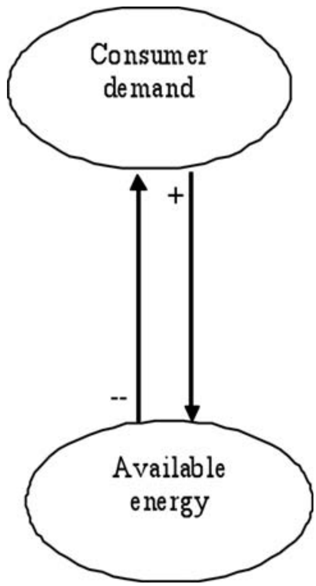

Figure 6. Casual Loop Diagram for Export

CASE STUDY

In this article, a medium sugar industry near Bijapur has been selected for case study. The details of the plant are documented in the following tables:

Factory Capacity:

Cane	3500 TCD
Boiler capacity	1200 TPD
Working pressure	32 kg/cm^2
In-house usage	2.5 MW

Cane recovery	0.3
Power selling cost	800 Rs/kW
Inventory cost	10 Rs/ton
Inventory purchase cost	200 Rs/ton
Power purchase cost	1000 Rs/kW

Table 2. Performance Table

Technology/capacity	Class 1	Class 2	Class 3
Boiler	2.2	1.8	1.2
In-house	0.2	0.5	0.9

Table 3. Cost Table

Technology/capacity	Class 1	Class 2	Class 3
Boiler	Rs 100,000	Rs 850,000	Rs 500,000
In-house	Rs 250,000	Rs 100,000	Rs 80,000

Simulation of the cogeneration system by system dynamics software is carried out to get different data used for the determination of energy management policy. Before simulating the model, we have to define the initial conditions and available capacities of a cogeneration system. These conditions and capacities are real information from the cogeneration plant for which the modeling is done. The real information is fed into the model with proper definitions and the software simulates the model based on this information. In this section, we define conditions and tabulate results so the tabulation can be used for the energy management. Figure 7 shows the flowchart of the steps followed in developing the simulation model in the present study.

The simulation model is formulated in terms of the casual loop diagrams discussed above. Figure 8 shows the simulation model built using STELLA.

The equations used for developing the simulation model in STELLA are as follows.

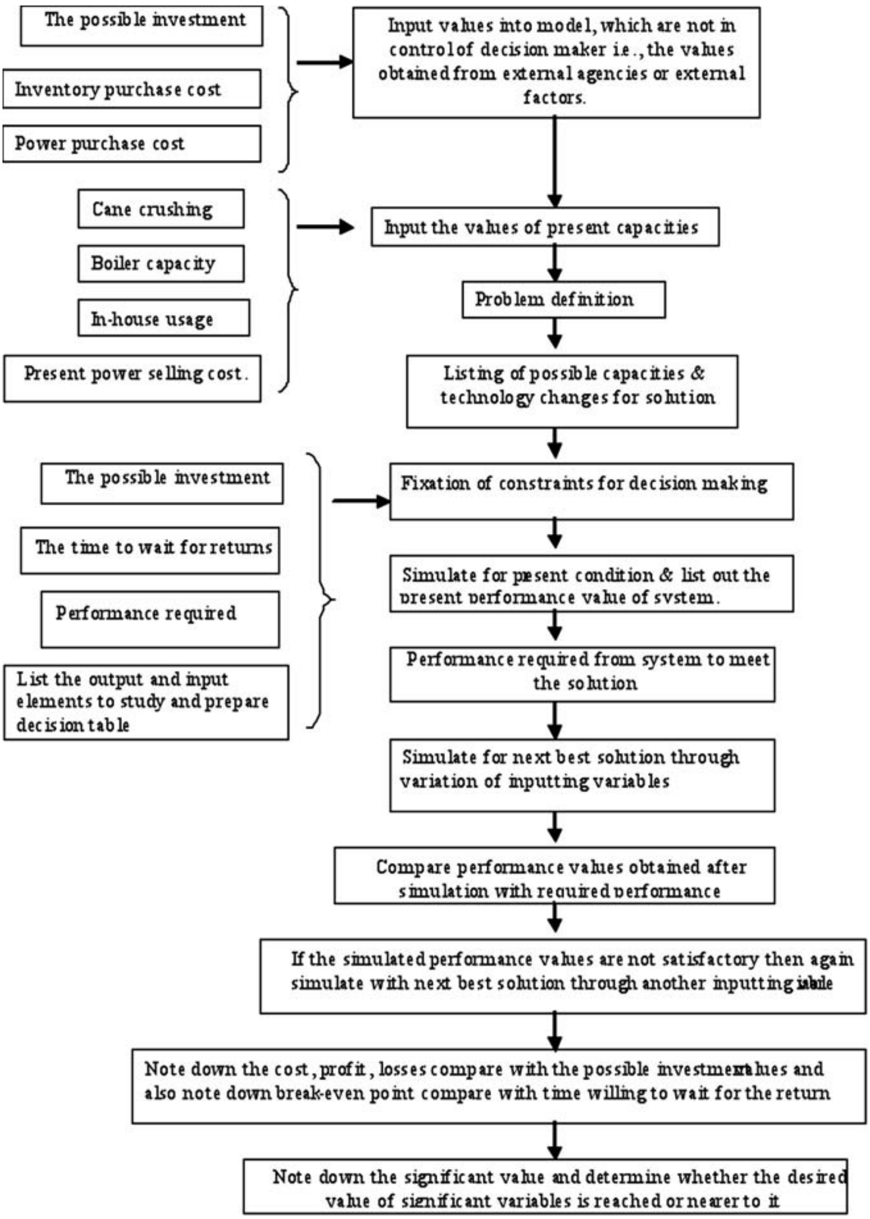

Figure 7. Flowchart Showing the Steps of Model Simulation

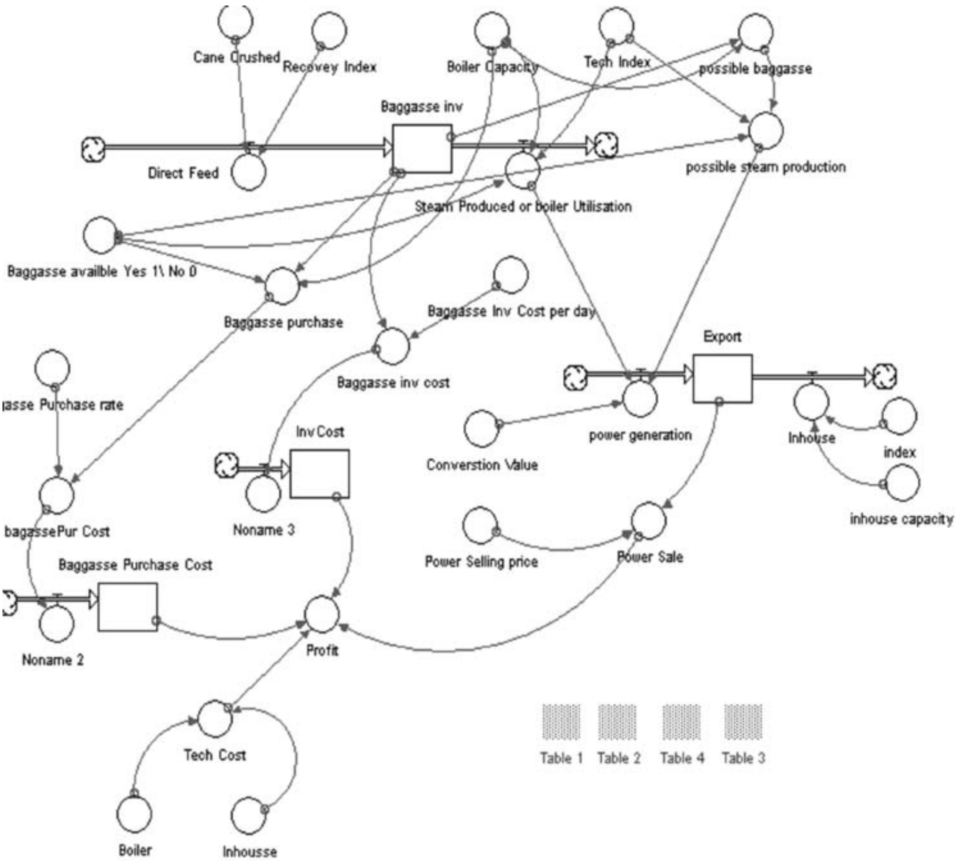

Figure 7. Flowchart Showing the Steps of Model Simulation

1. Bagasse used = (Direct feed to boiler) – (Boiler utilization)
2. Direct feed to boiler = (Recovery index) x (Cane crushed)
3. Boiler utilization = (Boiler capacity) x (Efficiency of boiler)
4. Export = (Power generation) – (Effective in-house usage)
5. Power generation = (Turbine efficiency) x (Boiler utilization)
6. Effective in house = (In-house use) x (Efficiency of system)
7. Total cost = (Technical cost) + (Inv purchase cost) + (Inv cost) + (Bagasse purchase cost) + (Tech cost in-house)
8. Inventory cost = (Bagasse inv) x (Inv maintenance cost)
9. Power cost = (Power purchase cost) – (Selling price)

10. Profit = (Selling price) – (Cost)
11. Power requirement = (Power generation) – (Effective in-house)

A decision table, shown in Table 4, is presented to show the simulation results. It is observed from the decision table that the policy 2 satisfies all the values of the requirement parameters.

CONCLUSION

In this article, a modeling approach is presented that meets a magnitude of requirements for analyzing energy management in sugar industries. It is shown that energy management activities can be improved through system dynamics modeling. The various applications point out the advantages of "system dynamics," particularly in energy management and assisting decision making procedures at the management level. The described model of cogeneration in sugar industry shows the application of the "system dynamics" approach and underlines the potential of this modeling approach for the energy management. System dynamics modeling allows us to visually express the decision rule and dependencies, and visualize the feedback loops in the system model for the cogeneration process. In this article, a simulation model that visualizes different relations among the elements in a cogeneration process is built. Based on this model, energy management policy is created making cogeneration a reliable, non-conventional energy source and making the continuous availability of bagasse for excess power generation and cost monitoring better known options, depending on power costs. The model is built in a simplified way; it deals with some structures in a highly aggregated level because of limited resources. The policies in this model can not be regarded as realistic forecasts; they just provide the hypothetical view for the policymakers to move the system outside the limited range of historical experience.

References

[1] Capehart, Turner and Kennedy, *Guide to Energy Management*, The Fairmont Press Inc., Lilburn, Georgia. 1997.
[2] C.G. Rajan, "Optimizing Energy Efficiency in Industries." Tada McGraw-Hill, 2001.
[3] CII (Confederation of Indian Industries) Report. www.cii.in.
[4] ISMA (Indian Sugar Mills Association) Report. www.indiansugar.com.

Table 4. Decision Table

Policy No.	Simulation No.	Reason to Simulate	Input Variables		Output Variables	Profit/Loss	Improvement Required	Remarks
			Index/Class	Tech Cost	Inventory			
0	1	Present status	0.8	0	1170	796000	Inventory usage	BEP after 1 month
1	2	Improve boiler efficiency	Class 2 1.8	Rs 85000	0	871000	Reduce tech cost	BEP after 1 month
2	3	Change class	Class 3 1.2	Rs 500000	0	871000	None	Satisfactory

[5] J.W. Forrester, "The Beginning of System Dynamics," International Meeting of the System Dynamics Society. Stuttgart, Germany, 1989.
[6] B. Richmond, "System Dynamics/System Thinking: Let's just get on With It," High Performance Systems Inc. Lebanon, NH.
[7] A. Ford, "System Dynamics and the Electric Power Industry," *System Dynamics Review*, Vol. 13, No. 1, John Wiley and Sons, 1997.
[8] ISEE Systems, Inc. Management/Business Analytics," Springer, 2002, pp. 58-61 and pp.87-104. (Available at http://www.iseesystems.com)
[9] World Alliance for Decentralized Energy (WADE). "Bagasse Cogeneration—Global Review and Potential." June 2004. www.localpower.org.
[10] S. Padmanabhan, et al, "Advancing Cogeneration in the Indian Sugar Industry." Report of USAID/New Delhi. Report 93-00, Arlington, VA. May 1993.

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