# System Dynamics Modelling Approach For Energy Management in a Sugar Industry.

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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. A comprehensive energy management program is not purely technical and its introduction also implies a new management discipline. It is multidisciplinary in nature and combines the skills of engineering, management and housekeeping. 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.In the industrial sector, there is considerable scope for improving energy efficiency. In industries the major consumers of energy are fertilizer, textile, sugar, cement, and steel. It has been estimated that the total conservation potential of this sector is around 25% of the total energy used by it. System Dynamics is an approach, which takes a causal view of reality, and uses quantitative means to investigate the dynamic behavior of socio-technical systems and their response to policy. In this paper we discuss how System Dynamics (SD) can aid as an effective management tool to resolve the complex dynamic issues of sugar industry energy management.The 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. Some computer software can be used to simulate the system behavior. These software simulate the system model with system dynamics approach. In this paper, the author has attempted to see how system dynamics modeling can be used for energy management in sugar industries.**Keywords- Energy Management, Sugar industry, Co-generation, System dynamics modeling.*

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## Introduction:

### Energy Management

The industrial sector uses about 50% of the total commercial energy available in India and the current national energy shortage is around 7 to 9%. Hence, major innovations are needed for reducing the energy intensity in manufacturing process and reduce the overall energy consumption and emission of pollutants in process industry while increasing the overall efficiency of the process. Such action will save the energy usage by the industry and improve its productivity and profitability, facilitate the electricity boards to meet the demands of the citizens without undue shortage and also help in minimizing the atmospheric pollution. Economic prosperity for the industry and nation can be achieved through the application of innovative energy efficiency measures.

Energy savings achieved through energy efficiency and conservation are highly cost effective and environmentally benign options compared to additional energy supply capacity creation. The services provided by energy in the form of appropriate light, heat, motion and cooling effect etc is more important rather than the amount of energy consumed itself. Therefore, the approach in all the energy consuming activity is to be shifted from “energy input” to the “effectiveness of the energy use” and “energy services”.

Energy Management is a technical and management function, the remit of which is to, monitor/measure, record and review, analyze, critically examine, generate options, evaluate options and optimize, alter or modify control energy flows through systems (management of fuels and deliveries, boiler houses, distribution systems, building services, plant, process equipment, polluting exhausts, effluents and wastes) so that energy is utilized with maximum efficiencies and maintain the targets. It embraces the disciplines of engineering and control, science, mathematics, economics, accountancy, design, operations research and information technology **[1].**

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 our country

On a macro level, the country is also starved of power, with the demand far outstripping the supply. The utilization of the extra power generation capability of the sugar industries, can aid in partly mitigating the situation. Hence, the present and future focus of the government and the Indian sugar industry will be, towards developing infrastructure for generating and utilizing this extra power generation capabilities.

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 efficiency aspects at the design / project stage itself**. [2]**

## Energy aspects of Sugar Industry

The sugar industry is energy intensive, requiring both electrical and thermal (steam) energy. The electrical and thermal areas are covered separately under the following headings **[3].**

**Table1**

| Electrical | Thermal |
|---|---|
| Cane preparation & handling | Evaporators |
| Milling | Clear juice heater |
| Juice preparation | Others |
| Evaporator, Crystallizer & Pans | |
| Pump house | |
| Centrifugals | |
| Others | |

The sugar industry is a unique industry with the following characteristics.

a) Highly energy intensive.

b) The by-product bagasse, is used as a fuel for generation of steam and power.

c) Depending on the system, excess power can be generated and sold to the grid.

The sugar industry consumes both steam and power. Hence, the plant should take-up steam and electricity saving projects together, to achieve maximum benefits**[4].**

## System Dynamics Modelling.

"System Dynamics" is a modeling concept for dynamic systems which has been developed by Jay W. Forrester at the Massachusetts Institute of Technology (MIT) in Cambridge. "System Dynamics" is a method which mutually links theories, procedures and philosophies which 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. 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 which 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. Some of the resulting advantages for the user of the "System Dynamics" concept are: **[5]**

- Stock-and-Flow diagrams provide intuitive system modules.
- Processes taking place are directly discernible.
- All dependencies and relationships are directly visible and understandable.
- All influencing factors are mapped via separate dynamic processes.
- Every process can be scaled and considered individually.
- Integration of qualitative processes and system elements is possible.
- Process groups can be formed and analyzed in context.
- Influencing processes can be considered dynamically in scenarios.
- All relationships can be considered and analyzed directly together.
- Further influencing processes can be integrated without any problems.
- Models from various disciplines can be mutually combined.
- A 'control desk' can be created for executing and modifying scenario simulations.

The discipline holds dynamic behavior of complex systems emanates endogenously from the system structure consisting of stocks and flows embedded in feedback loops, which form the basic unit of analysis in a system dynamics (SD) model. As opposed to other computer simulation tools such as agent-based modeling which are referred to as bottom-up computing where computerized individual agents interact based on a set of few rules, and the researcher analyzes the emergent outcomes of the simulated interaction, SD has been labeled a top-down approach, where the modeler(s) define variables and all relationships between variables in advance and then simulate their interaction. SD modeling has predominantly been used for policy analysis. Models can have dozens of hundreds or even thousands of variables, equations, and feedback loops. As Forrester points out, SD models are constructed on the basis of three information sources, (1) numeric data, (2) textual accounts, and (3) the mental models of modelers and others involved in the model building process. According to Forrester, the richest source for modeling lies in the mental models while numeric data account for a relatively small fraction of data of any problem under study. Forrester's argument for including soft information into models is straightforward if relying only on hard numeric data, the model would inevitably exclude critical information and implicitly assume that those the mental models among modelers.

The basic building block of SD is the stock or the level, which is used to represent anything that accumulates. The second building block is the flow or the rate, which is used to represent activities that will change the magnitude of stock in a system. The third one is called connectors to transmit information and inputs that are used to regulate flows. The last building block is the converter, which contain equations to generate an output value for each time period, and often take in information and transform it for use by another variable in the model. They are also handy for storing constant values**.[6], [7], [8].**

## System Dynamics Methodology.

**Table2**

| Phases | Steps |
| --- | --- |
| 1. Problem structuring | 1. Identify problems or issues of concern to management<br>2. Collect preliminary information and data |
| 2. Causal loop modeling | 1. Identify main variables<br>2. Prepare behavior over time graphs (reference mode)<br>3. Develop causal loop diagram(influence diagram)<br>4. Analysis loop behavior over time<br>5. Identify system archetypes<br>6. Identify key leverage points<br>7. Develop intervention strategies |
| 3. Dynamic modeling | 1. Develop a system map or rich picture<br>2. Define variable types and construct stock-flow diagram<br>3. Collect detail information and data<br>4. Develop a simulation model<br>5. Determine model's properties (e.g. initial value, simulation interval, time horizon of simulation)<br>6. Compare model behavior with historical trends or hypothesized reference mode<br>7. Validate the model<br>8. Perform sensitivity analysis<br>9. Design and analyze tactics<br>10. Develop and test strategies |

| | |
|---|---|
| 4. Scenario planning and modeling | 1. Plant general scope of scenarios<br>2. Identify key drivers of change and keynote uncertainties<br>3. Construct forced and learning scenarios<br>4. Simulate scenarios with model<br>5. Evaluate robustness of the tactics and strategies |
| 5. Implementation and organizational learning | 1. Prepare a report and presentation to management team<br>2. Communicate results and insights of proposed intervention to stakeholders<br>3. Develop a micro world and learning lab based on the simulation model<br>4. Use learning lab to examine mental models and facilitate learning |

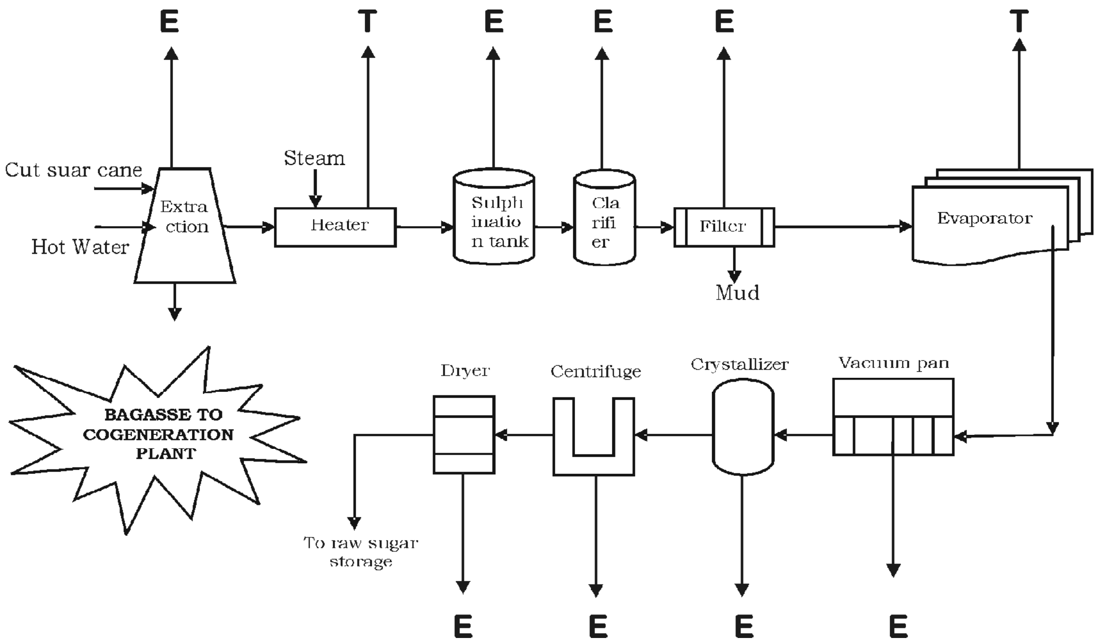
System dynamics uses computer simulation software such as Powersim, Stella,iThink, Vensim, Dynamo as its tool. All of them work basically the same, but of course each of them has its own characteristics. The tool to be used in this study is **Stella. [5]**

## System Dynamics Modeling for Energy in Sugar Industry

System dynamics modelling has been used for strategic energy planning and policy analysis for more than twenty-five years. The story begins with the world modelling projects conducted in the early 1970s by the System Dynamics Group at the Massachusetts Institute of Technology. During these projects the WORLD2 and WORLD3 models were created to examine the "predicament of mankind" — that is, the long term socioeconomic interactions that cause, and ultimately limit, the exponential growth of the world's population and industrial output **[9].**

Basically to model a system in system dynamics, a system must be subdivided in such a way that a subdivided element 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 industry system can be subdivided by the number of processes. Each process is considered as a subsystem for energy consumption. Each subsystem in turn can be subdivided until independent elements are obtained. The following figure shows the process flow diagram of a sugar industry.




**E-Electrical Energy**

**T-Thermal Energy**

**Figure1: Flow Diagram of Sugar Manufacturing Process**

These processes can be considered as subsystems of a sugar industry.

## Co-Generation in a Sugar Plant.

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, and is sent to the boiler to produce steam and electricity for the factory. The fact that the sugarcane plant provides its own source of energy for sugar production in the form of bagasse has long been a special feature of the sugar industry. In the traditional approach, sugar factories and distilleries co-generate just enough steam and electricity to meet their on-site needs. Boilers and steam generators are typically run inefficiently in order to dispose of as much of the bagasse produced from crushing the cane as possible. Some older factories purchase oil or electricity, because their steam generating technologies and boilers are extremely inefficient. Any factory 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. **[12], [13].**

Co-generation, as shown in the figure can be considered as one of the subsystems in the sugar manufacturing process.

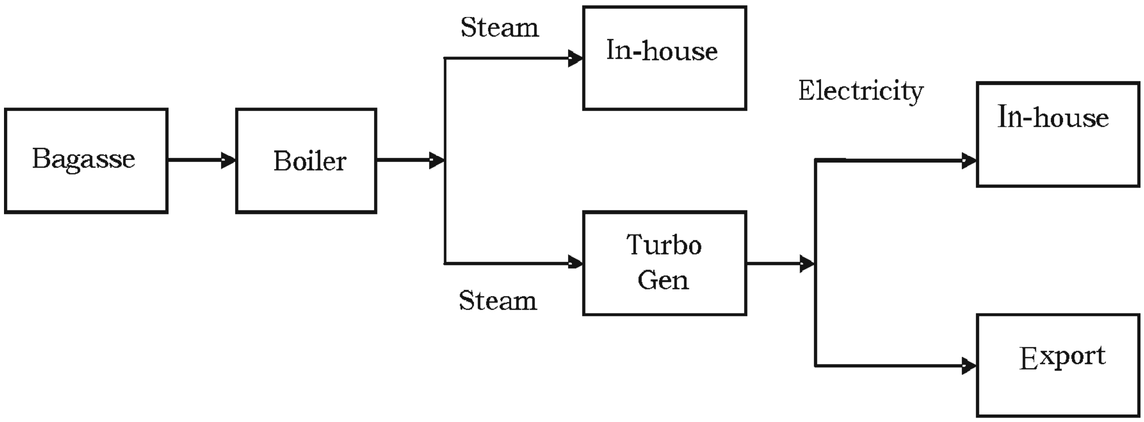



**Figure2: Cogeneration subsystem**

A well-designed and operated cogeneration scheme will always provide betterenergy efficiency than conventional plant, leading to both energy and cost savings. A single fuel is used to generate heat and electricity, so cost savings are dependent on the price-differential between the primary energy fuel and the bought-in electricity 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. As a rough guide, cogeneration is likely to be suitable where there is a fairly constant demand for heat for at least 4,500 hours in the year.

The sugar plants have been adopting bagasse co-generation right from the beginning. However, the co-generation has been restricted to generating power and steam only to meet the operational requirements of the plant. Only in the recent years, with the increasing power demand and shortage, commercial cogeneration has been found to be attractive, both from the state point of view as well as the sugar plant point of view.

The sugar plant derives additional revenue by selling power to the grid, while the state is able to marginally reduce the 'demand-supply' gap, with reduced investments.

## Elements of Cogeneration system

- Baggasse.
- Boiler.
- Generator.
- In House.
- Export.

### Relation between elements & 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 which influence the energy aspects in a sugar industry. Other elements which 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 which will influence the behavior of individual systems.

The list of sub-subsystems and elements of these sub-subsystems are shown in the table below.

**Table 3**

| 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 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 |

From the table, a system dynamic loop diagram for each subsystem is drawn with detailed rate of influence.

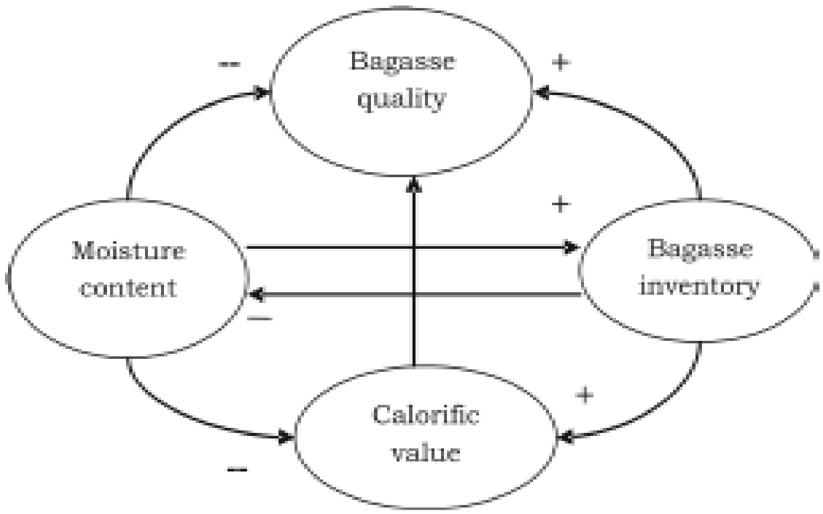



**Figure 3: A system dynamics loop for bagasse sub system.**

1] **Content of water:** Since 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.

2] **Calorific value:** A good bagasse always has high calorific value. Hence it is taken as +ve.

3] **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.

After constructing the loop diagram for all subsystems 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 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.

Up to this a single sub-subsystem simulation is attempted by considering each as a single system for system dynamics modeling. Similarly, simulating all the sub-systems, considering each one as a defined element for the subsystem and considering each subsystem as the defined element for the whole sugar industry system.

Finally for the simulation of the sugar industry model a number of elements are already considered while considering single sub-subsystem. Therefore sugar industry model will have more independent elements and the accuracy of the system behavior is also more.

With system dynamics, a sugar industry can be simulated with respect to energy exchanges. The simulation will show the dynamic behavior of energy situation in the sugar industry. Through variation of the independent elements for the input to the system model, every time a different situation can be created. Analyzing these situations energy management can be easily done.

**Introduction to Stella**

**(Systems Thinking Educational Learning Laboratory with Animation)**

**STELLA** is a computer simulation program, which provides a framework and an easy-to-understand graphical interface for observing the quantitative interaction of variables within a system. The graphical interface can be used to describe and analyze very complex physical, chemical, biological, and social systems. Model builders and users, however, are not overburdened with complexity because all STELLA models are made up of only four building blocks, pictured in Figure 2.

**STELLA** is not the only modeling software available. Vensim, Powersim, and DYNAMO are three other software packages that modelers frequently use.

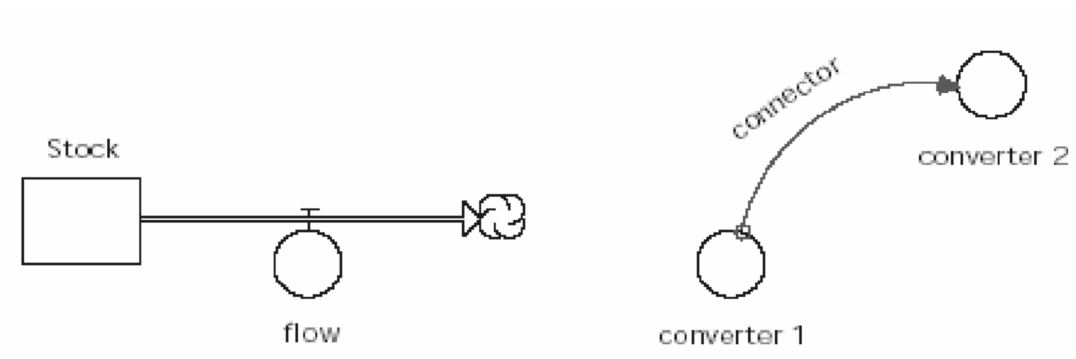



**Figure 4: Representations of a stock, flow, converter, and connector**

**Stock :** A stock is a generic symbol for anything that accumulates or drains.

**Flow :** A flow is the rate of change of a stock.

**Converter:** A converter is used to take input data and manipulate or convert that input into some output signal.

**Connector:** A connector is an arrow that allows information to pass between converters and converters, stocks and converters, stocks and flows, and converters and flows. In Figure 2 above, the connector from converter 1 to converter 2 means that converter 2 is a function of converter 1; in other words, converter 1 affects converter 2.

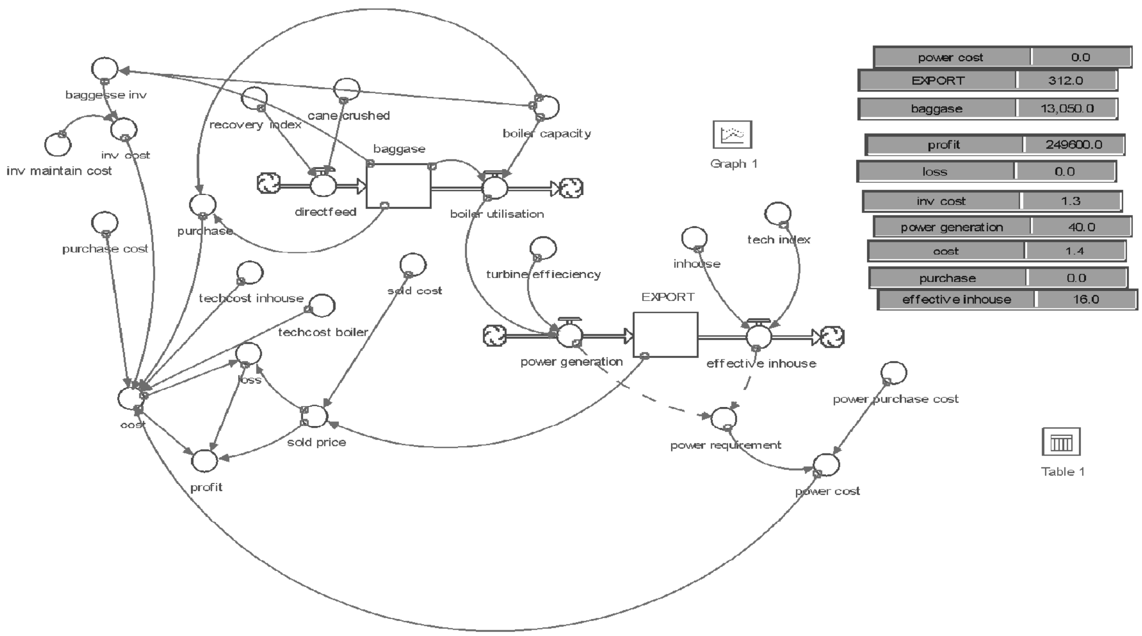



**Figure5: Simulation model**

## Problem Definition:

The sugar production process is energy-intensive, requiring both steam and electricity. Historically, sugar mills have been designed to meet their energy requirements by burning bagasse. This was seen as an economic means of producing electricity whilst cheaply disposing of bagasse. However, as there was little potential for the sale of electricity to the grid, efficiency in the process was a hindrance rather than a bonus.

Co–generation is a good source for energy but it is not reliable for continuous utilization, hence it is not becoming a source of greater importance like other power sources.

## Causes of Problem

Bagasse is used as fuel and the bagasse is obtained after crushing of cane. The cane production and crushing are bound by seasonal, demand fluctuations.

## Solutions for the Problem

To make co-generation a source of greater importance and make it a profit making entity of sugar industry the solution is “Energy Management”. Improve the production strategies, present attractive options as they offer flexibility in producing varied quantities of sugar, ethanol and electricity depending on prevailing market conditions.

## Simulation of co-generation for energy management:

Simulation of co-generation 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 & available capacities of a co-generation system. These conditions & capacities are real information of co-generation of factories for which modeling is done. The real information is fed into the model with proper definitions & the software simulates the model based on this information.. In this section we define conditions & tabulate results such that tabulation can be used for the energy management.

## Definition of factory capacity

These capacities will affect the performance of co-generation system. These behave as constraints of system beyond which co-generation cannot perform efficiently.

Modernization of capacities will increase the performance but with increase in the cost. To increase a specific capacity will have its own cost known as technical-cost, adoption of new technology will increase by value known as technical-index. This technology index may increase capacity as a whole, or can increase efficiencies of present capacity. In context of this project the efficiency improvements are considered.

The capacities of co-generation system

1. Cane crushing
2. Boiler capacity
3. Generator & boiler efficiencies.

**1. Cane crushing:**

Each factory has a fixed crushing capacity depending on the type of sugar industry such as large, medium & small. Baggasse will be obtained after crushing the cane. A recovery factor will determine the baggasse available from the volume of cane crushed & this factor is dependent upon the quality of cane crushed.

**2. Boiler capacity:**

The bagasse produced is burnt in the boiler. The boiler is used to rise the temperature of water present to get steam through which it generates power, using bagasse as the fuel. The boiler capacity can be defined as the amount of bagasse it can burn at any instant. But all boilers can't burn to their full capacities and it depends on the boiler efficiency. Hence, the utilization of bagasse as fuel will be affected by boiler efficiency.

Bagasse utilization capacity = Boiler Capacity * Boiler Efficiency.

## Choice of energy management variable.

The energy management variables are the variables based on which energy management policy will be determined. These variables indicate energy scarcity & availability in the system. These variables will be influenced by capacities of system. And change in capacities, changes the energy condition of the system. The choice of variables must be such that their information should be valuable from energy management point of view.

In co-generation system the variables affecting energy are,

- Cane crushing
- Boiler capacity
- Cost of Inventory. Purchase of bagasse, Power purchase, modernization costs technological-cost).
- In-house technological-cost.

**1. Cane Crushing:**

It is the variable for the energy management because the volume of crushing determines the bagasse availability.Variation in cane crushing varies the fuel availability.

**2. Boiler Capacity:**

It determine useful fuel i.e., energy that can be utilized

**3. Costs of:**

Inventories, bagasse purchase, power purchase, modernization, in-house will indicate the energy condition in system with respect to cost which will be helpful for the break even analysis.

## Determination of study parameters

The study parameters are those which help to study the system behavior with respect to energy management. Any number of parameters can be considered but these parameters must be present in the system. Elements of system can be the study parameters. For energy management, the study of break even point & cost are important. Therefore, in this system the elements, which can indicate these important factors, are considered. These are;

- Profit.
- Loss.
- Cost.

Considering these three elements, other elements can be studied with respect to these elements.

## Input variables

These are the data variables input to model to simulate it. These input data can be capacity data, performance data, cost data, etc. Inputting data is most significant step in simulation part, the unrealistic data simulate unrealistic result which is not useful for the decision making process. Therefore, it is important to define the characteristics of input variables. These considerations make a reliable input. The input variable must have control from decision maker. This means input variable given by decision maker must be within the scope of system considered. An outside system element should not have control over it. The input variable must have definite reason behind it. The input variable must be a number.

**Table 4 : 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 5 : Cost table**

| Technology/capacity | Class 1 | Class 2 | Class 3 |
|---|---|---|---|
| Boiler | 100000 | 850000 | 500000 |
| In-house | 250000 | 100000 | 80000 |

The capacity input:

- Crushing rate.
- Boiler capacity
- Power selling cost

Since all the above inputs are within decision maker's control, the decision maker has the choice to choose any value for the simulation to make a decision.But inventory cost, power purchase cost, bagasse purchase costs are not in control of the decision maker, and these are controlled by external elements which are beyond scope of system.

The input variables are:

- Index values
- Capacity of boiler
- Cane crushing
- Power selling cost

## Simulations for energy management policy

The energy management policy is policy determined after the simulation for different circumstances in the system. This policy gives the decision maker a choice to adopt the policy to achieve better energy management. To get this policy, system model is simulated a number of times with different values of input variable. These simulations lead to different circumstances regarding energy management elements like break even point, profit, loss, etc.

To simulate the model, the following steps are followed

**Step 1:** Input values into model, which are not in control of decision maker i.e., the values obtained from external agencies or external factors. They are:

- Inventory maintenance cost
- Inventory purchase cost
- Power purchase cost

Obtained index values from technologist or manufacturing industries (exports).

[Note: Index values choice is in control of decision maker but the fixation of value depends upon experts].

**Step 2**: Input the values of present capacities. They are:

- Cane crushing
- Boiler capacity
- In-house usage
- Present power selling cost.

**Step 3**: Problem definition.

**Step 4:** Listing of possible capacities & technology changes for solution.

**Step5**: Fixation of constraints for decision-making

- The possible investment by decision maker
- Performance required from system to meet the solution
- The time a decision maker should wait for returns
- List the output and input elements to study and prepare decision table

**Step6:** Simulate for present condition & list out the present performance value of system.

**Step7:** Simulate for next best solution through variation of inputting variables.

**Step8:** Compare performance values obtained after simulation with required performance

**Step9:** If the simulated performance values are not satisfactory then again simulate with next best solution through another inputting variable

**Step10:**Note down the cost, profit, losses compare with the possible investment values & also note down break-even point compare with time willing to wait for the return.

**Step11:**Note down the significant value & determine whether the desired value of significant variables is reached or nearer to it.

## The Simulation Study of Sugar Industry. (A Case Study)

In this paper, a medium sized sugar industry near Bijapur has been selected. Some of the details are

**Factory Capacity:**

- Cane crushing -3500 TCD
- Boiler capacity-1200 TPD
- In house usage- 2.5 Mw
- Cane recovery- 0.3
- Power selling cost- 800 Rs/kw

**Step 1:** Inventory cost = 10 Rs/ton Inventory purchase cost = 200Rs/ton Power purchase cost = 1000 Rs/kw

**Table 6 : 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 7 : Cost table**

| Technology/capacity | Class 1 | Class 2 | Class 3 |
|---|---|---|---|
| Boiler | 100000 | 850000 | 500000 |
| In-house | 250000 | 100000 | 80000 |

**Step2:** Input values for present capacities in model

**Step3:** Problem Definition

From the simulation with present capacities industry has 1,170 tons of bagasse as inventory. Therefore industry wants to utilize this bagasse

**Step4:** The possible capacity change is Boiler Capacity. The possible technical changes are class 1, 2, 3

**Step5:** Decision constraints

- The investment limit Rs 12,00,000.
- Boiler capacity extension to consume 1.170 tons of bagasse
- Investment return time - 1 month
- List of input variables (a) Index value (b) Technical cost
- List of out put variables (a) Inventory

**Table 8 : Preparation of 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 | 7,96,000 | Inventory usage | BEP after 1 month |
| 1 | 2 | Improve Boiler Capacity | Class2 1.8 | Rs.8,50,000 | 0 | 8,71,000 | Reduce Tech cost | BEP after 1 month |
| 2 | 3 | Change class | Class3 1.2 | Rs.5,00,000 | 0 | 8,71,000 | No | satisfactory |

**Step6:** Policy 0 simulation

**Step7:** Policy 1 and Policy 2 simulation

**Step8:** Comparison

| | **Policy 1** | **Policy 2** |
|---|---|---|
| Inventory | 0 | 0 |
| Profit | 7961200 | 8710000 |
| BEP | 1 Month | 1 Month |

**Step 9:** Policy 3

Profit – Rs.87,10,000.

BEP - zero (at initial month only)

**Step10:** Comparing policy 3 parameter values with required parameter values

- Investment required 500000
- Investment limit 120000 Therefore investment parameter value satisfies
- Break even point is within desired period i.e. of 1 month
- Inventory is consumed completely

The **policy 3** satisfies all the values of the requirement parameters.

### Energy Management Policy in Co-Generation:

The bagasse is burnt in co-generation to have the steam for sugar process. But surplus bagasse is not utilized in most of factories. Some factories utilized this extra bagasse to generate electric energy, which will be sold to state grid. Since seasonal fluctuations will not permit continuous selling of power to the grid. That is why co-generation is becoming non-reliable, non-conventional source of energy. Therefore the policy here is make co-generation reliable, non-conventional energy source.

The policy is to have:

1. The continuous resource (bagasse) to provide continuous power i.e. to export to grid.
2. Cost monitoring to know better options depending upon power cost (Price) available at that time.

## Conclusion

The system dynamics approach can be a basic tool to energy management of systems. Model simulation through system dynamics software reduces the time of collecting the data and calculation. Due to flexibility in varying the inputs it is very easy to have a number of situations for analysis. Based on these analyses an energy management policy can be formed and can be checked. A better policy or formula will evolve by continuous refinement of the system model and element determination.

Whole sugar industry can be modeled to obtain generalized policy for energy management of complete sugar industries. Introducing more elements and increasing boundary conditions of system a more realistic and reliable simulation can be achieved.

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