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A conceptual model for energy management in the steel industry: A Soft System Methodology (SSM) approach

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Abstract
This paper aims to use Soft Systems Methodology (SSM) to develop the steel industry's energy management framework. It proposes a soft system approach to analyze the complex situation of developing a support system for energy management. This approach consists of identifying the system scope, discovering underlying problems within, deriving a conceptual model from the complex situation, and identifying possible actors and activities to bring the conceptual model closer to reality. The identified activities could serve as a guideline for designing and developing an effective energy management framework in the steel industry. The result might also be further developed to drive the feasible, desirable changes into real implementation strategies and action plans. Currently, there is very limited SSM academic research in energy management. Hence the researchers sincerely hope that this study might help to drive the SSM methodology application in this field, in conjunction with the body of knowledge of Industrial and Systems Engineering (IISE).

Keywords:
Energy;
Steel;
Manufacturing;
Framework;
Soft System Methodology (SSM);

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INTRODUCTION

Global warming is a serious problem that everyone should be aware of. Reducing greenhouse gas (GHG) emissions is one of the most effective measures to reduce global warming. One of the major contributors to greenhouse gas emissions is the manufacturing industry, so reducing GHG emissions from manufacturing facilities has been a topic of research interest for decades. In addition, reducing energy consumption also helps companies save costs and become more competitive. Effective energy management is, therefore, a key factor in improving competitive advantage and promoting sustainable and environmentally friendly industrial practices.

The steel industry nowadays contributes around 3.8% of the world's GDP, generates US$ 2.9 Trillion economically, and facilitates 96 million jobs globally [1]. Furthermore, steel production worldwide is still increasing [2, 3, 4]. Steel Committee of the Organization for Economic Co-operation and Development (OECD) stated that the South East Asia Iron and Steel Institute (SEAISI) forecasted that Indonesian steel consumption is projected to be 21.4 million tons in 2025, rising from 15.09 million tons in 2020 [5]. SEAISI also predicted that Indonesia would see its steel demand reach or exceed pre-pandemic levels due to the surge of automotive production in 2021 [6]. This increase in steel consumption will create a multiplier effect on all stakeholders of the national steel industry. Still, on the other hand, it will also increase energy consumption, increasing GHG emissions.

As illustrated in Figure 1, the 2019 Indonesia Energy Outlook (IEO) showed that Indonesia's final energy demand in 2025 is projected to be 170.8 MTOE, 154.7 MTOE and 150.1 MTOE 2025. In the same scenario, 548.8 MTOE, 481.1 MTOE, and 424.2 MTOE in 2050.

Figure 1. Indonesia steel production, import, export, and consumption figures (MT/year) [5]

Both are projected in normal, PB and RK scenarios. In 2025, energy demand in all scenarios will be dominated by the transport sector (35%) and in 2050 by the industrial sector (37-42%) [7].

The IEO also indicated that six industrial subsectors are classified as major energy consumers, as shown in Figure 2. These six major industries are expected to account for 87% of the industry's total energy consumption. Based on the United Nations Framework Convention on Climate Change (UNFCCC) NDC document shown in Figure 3, it can be concluded that future energy demand will increase throughout the year. Additionally, the UNFCCC projects the impact of this increase on increasing greenhouse gas emissions, as shown in Figure 4.

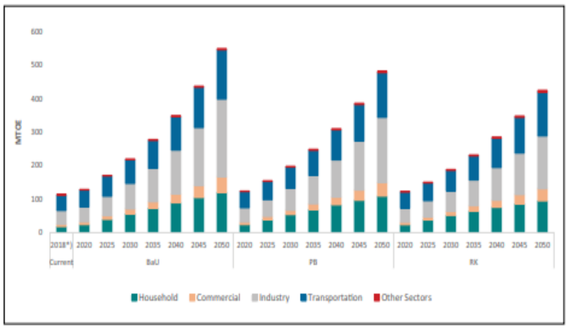

Figure 2. Projected Final Energy Demand [7]

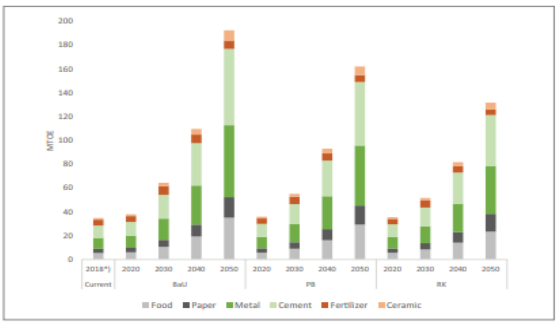

Figure 3. Projected Energy Demand in Six Major Industrial Sub-sectors [7]

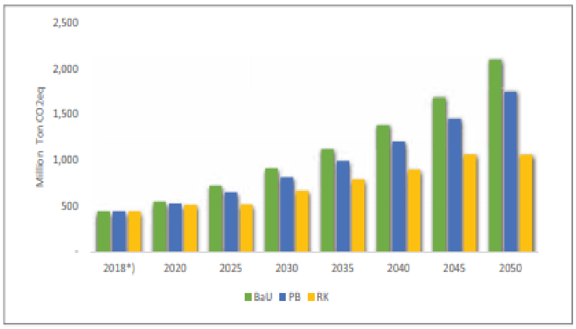

Figure 4. Projected GHG Emission Growth [7]

On the other hand, Figure 5 illustrates that although energy consumption to produce crude steel has been reduced over the years due to process and technology development, there has been no significant reduction in the recent 20 years [8]. This is because the process and technology development has reached their bottleneck, and the latest advancements have not been fully implemented due to the high investment and long return period.

Based on the situation above, a conceptual model of energy management needs to be developed to mitigate the ever-increasing energy consumption and GHG emissions, especially in the steel industry, which has been identified as a key stakeholder. The situation is highly complex as different stakeholders may have their own perspectives, beliefs, and values about what the issue represents and how it is addressed. Different aspects of what is considered problematic may also be related to each other.

Changing one aspect can randomly affect other aspects. Therefore, it is important to have a holistic understanding of the connections between the various aspects of the situation. Moreover, the subjectivity of various stakeholders requires researchers to work with each stakeholder.

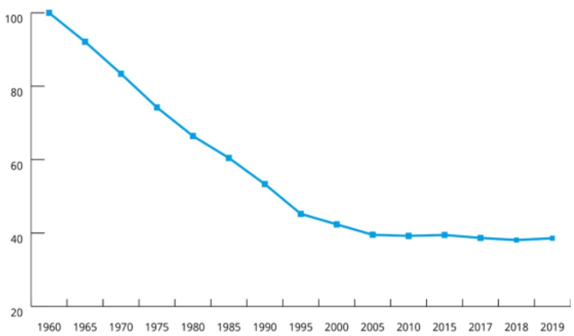

Figure 5. Indexed Global Energy Consumption per Ton of Crude Steel Production [8]

The aim is to precisely define the problem and future change direction and discern a codified conceptual model from the surrounding confusion. It may be necessary to examine the point of view of

METHODS

Soft Systems Methodology (SSM) was selected due to its ability to analyze and systematize the complex situation and generate a conceptual model as an output [9].

Novelty

SSM has been widely used over the years. In recent years alone, SSM was found to be used to design frameworks for: COVID-19 mitigation policy [10], agricultural research [11], fishery management [12], social engineering [13], technology education [14], change management [15], supply chain sustainability [16], procurement [17], non-verbal communication in tourism [18], technology adaptation [19], knowledge elicitation [20], pollution mitigation [21], data improvement [22], healthcare competence assessment [23], and supply chain model [24]. However, there is little mention of SSM applications to analyze complex problems and design frameworks in steel manufacturing and energy management.

Method

Soft system thinking explores a complex real system phenomenon that arises in human activities. Rather than reducing the complexity with various assumptions so that it can be mathematically modeled (hard system), soft systems try to include the differing perspectives of multiple stakeholders involved [9].

SSM could be used to analyze problems or situations, even when the problem cannot be formulated due to its high complexity. Such problems usually have their complicated ends, goals, and objectives [25]. The major supporting causes in selecting SSM in this study is that SSM sequences are not forced on its practitioners. The study can begin at each stage, with iterations and backtracking allowed or supported to better perceive and systemize the complex real-world problem. Another cause as stated by Zuniawan [21], that the Human component in SSM will determine characteristics of the organization, providing meaning to their situation and determining their own goals for the organization.

This interpretative approach to perceiving a systematized model from the surrounding chaos is strongly influenced by Vickers' depiction of the importance of a system in dealing with human complexity. Checkland developed SSM in the 1970s as an organized way of systematizing complex situations in the real world based on systems thinking. Prior studies show that SSM methodology could be described best as a seven-stage model below [9][25]:

1) Stage 1: Observe the unstructured problem situation.
2) Stage 2: Organize the problem situation by defining relevant purposeful systems.
3) Stage 3: Clarify what the system exists to achieve by defining root definitions of relevant activity systems.
4) Stage 4: Derive conceptual models from the stages above.
5) Stage 5: Compare conceptual models with problem situations in the real world.
6) Stage 6: Analyze the feasible and desirable changes.
7) Stage 7: Take action to involve stakeholders and implement the change.

In Stages 1 and 2, the context of the problem is understood, and relevant information and relationships are identified. A detailed description of the problem situation can then be developed and presented as a meaningful diagram. A rich picture is used to illustrate the situation, including the organizational units of interest, the relationships between them, and the obvious key roles, problems, and areas of conflict [26]. There is no formal method to develop rich pictures, but they are usually presented visually as overview maps or mind maps. The positive points of the rich picture diagram are:

1. It is an ideal tool for illustrating complicated and problematic situations.
2. It could provide linkages between elements and relationships that are interwoven, directly or not, and are easier to see.
3. Facilitate identification of problem owners, potential problems, and potential conflicts.
4. Assist in limiting and scoping problems.

Stage 3 defines a root definition that represents the essence of the actual problem. The root definition is concise, streamlined, and contains all the information necessary to understand human activity systems. A well-formulated root definition must explicitly generate each element of CATWOE, which provides a mechanism or checklist for testing root definitions and ensuring that the words chosen are as accurate as possible, representing the best selection of meanings [9]:

1. Customer (C): people affected by the system.
2. Actor (A): people participating in the system.
3. Transformation (T): process carried out by the system or conversion from input to output.
4. Weltanschauung (W): world view.
5. Ownership (O): people with power to decide the usefulness of the system.

6. Environmental constraints (E): external factors that could restrict the transformation.

Stage 4 creates a model of the activity system needed to achieve the transformations described in the root definition. A conceptual model is a systematic representation of a human activity system, built on the underlying definition of the system, usually in the form of a structured set of imperative verbs. A model contains the minimum number of activities required and shows the relationships between them.

As shown in Figure 6, model building is performed by stages 4.a and 4.b. The formal system concept, Level 4.a, consists of generic models of any human activity system that can be used to ensure that the models produced are free of inherent flaws. Stage 4.b, Other Systems Thinking, consists of modifying or transforming the model, if necessary, into other forms deemed suitable for the problem.

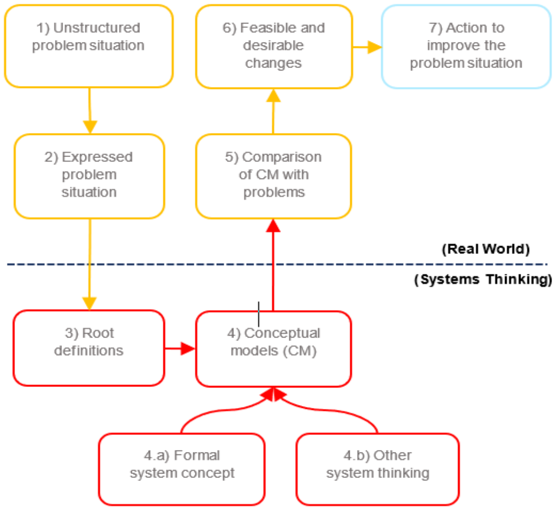

Figure 6. Summary of SSM Seven-Stage Model

Stage 5 identifies activities in a conceptual model, then compare the conceptual model to the real world to find possible changes that could be done. Methods for making comparisons are [8]:
1. Unstructured discussion.
2. Model structured questions in a matrix.
3. Scenario or Dynamic Modeling.
4. Try to model the real world using the same structure as the conceptual model.

Stage 6 differentiates between the model and the real world and generates actions that could be introduced into the problem. Changes should be discussed with stakeholders and are arguably desirable and culturally feasible given the people involved, prevailing attitudes, and shared experiences and biases.

Stage 7 is all about implementing the proposed changes. The problem status is then changed and becomes the new problem status, which indicates that the process is cyclic.

RESULTS AND DISCUSSION

Stage 1: Identifying the Problem

The 5W1H method is used to better identify, collect, and analyze issues in the steel industry. As shown in Table 1, Collection is done through brainstorming and closed interviews, whereas validation is done through focused group discussions.

Stage 2: Structuring the Problem

Structuring energy management process in a steel plant using a rich picture diagram. Figure 7 illustrates the structure.

Stage 3: Clarifying Root Definition

Applying and classifying the root definition in CATWOE Question and Answers. Table 2 provides this clarification.

Table1. Problem Identification

5W1H	Energy management
What	1. Steel industry is a major energy consumer (20-40% of production cost) and hence GHG producer. 2. There is an urgent need to identify energy-saving opportunities or improve energy usage effectiveness, but it is a complex problem with multiple stakeholders involved.
Where	A steel plant located in Bekasi, Indonesia.
When	It has been an ongoing problem for 20 years.
Why	1. The steel industry is a highly competitive sector, so even a slight reduction in energy consumption might drive a lower production cost and improve competitiveness. 2. Indonesia has ratified the UNFCCC convention, which states that the emission target in the energy sector in 2030 is 1,355 million Ton CO_2, with 29% of the emission reduction target.
Who	1. Top management. 2. Policymaker. 3. Energy suppliers. 4. Purchasers, marketers & planners. 5. Engineers & data scientists.
How	1. Record energy consumption. 2. Analyze energy consumption. 3. Analyze GHG emissions. 4. Optimize plant energy consumption to reduce energy consumption and GHG emission.

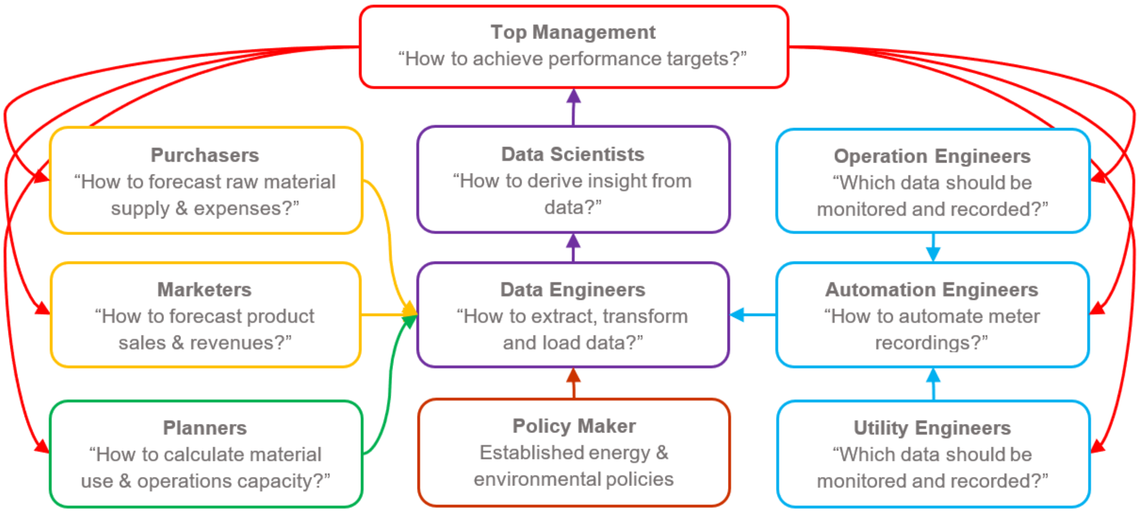

Figure 7. Structuring energy management in steel plant using rich picture diagram

Table 2. CATWOE Question and Answers

Element	Question	Answer
Customers	Who are the system beneficiaries?	The ones that manage and oversee manufacturing operations and production cost (operations director).
Actors	Who transforms inputs into outputs?	The ones that operate manufacturing facilities (engineers, supervisors, and operators).
Transformation	What transformation exists?	The transformations needed to arrange energy data into structured analysis.
Worldview	What is the reason for this transformation?	Better data visibility & visualized data analysis to derive insights for energy conservation.
Owners	Who can stop or change this transformation?	The ones that control manufacturing facilities (operations manager).
Environment	What constraints are in the immediate surroundings of this transformation?	Environment constraints, shop floor facilities, and data management capability.

With Figure 7 as basis, root definitions are constructed as elements of CATWOE shown in Table 2. An inclusive root definition is then defined as support system to capture and convert energy consumption data into organized analysis reports. Insights could later be derived from the analysis reports, to enable stakeholders to find energy conservation opportunities.

Stage 4: Deriving Conceptual Model

The conceptual model will describe all activities related with energy management based on root definitions depicted in Figure 8. The system would record and analyze various data to measure production yield, energy use, and energy losses to enable stakeholders to find conservation opportunities. For example, identification of energy-inefficient machines to see if repair or modification could be performed. Recorded data needed usually includes meter readings, production yield data, activity data, and management objectives targets.

Stage 5 and Stage 6: Comparing Conceptual Model with Real World situation, and Identification of Changes

The comparison is to find feasible and desirable changes that could be done to bring reality closer to the conceptual model. Table 3 compares the conceptual model activities with what happens in real world and what feasible and desirable changes could be made to address the problem.

Stage 7: Take Action to Involve Stakeholders and Implement the Change

The feasible and desirable changes from Table 3 could be developed and implemented. However, because the implementation requires further considerations such as project timeline, budget, and investment return, Stage 7 results cannot be shown when this article was written.

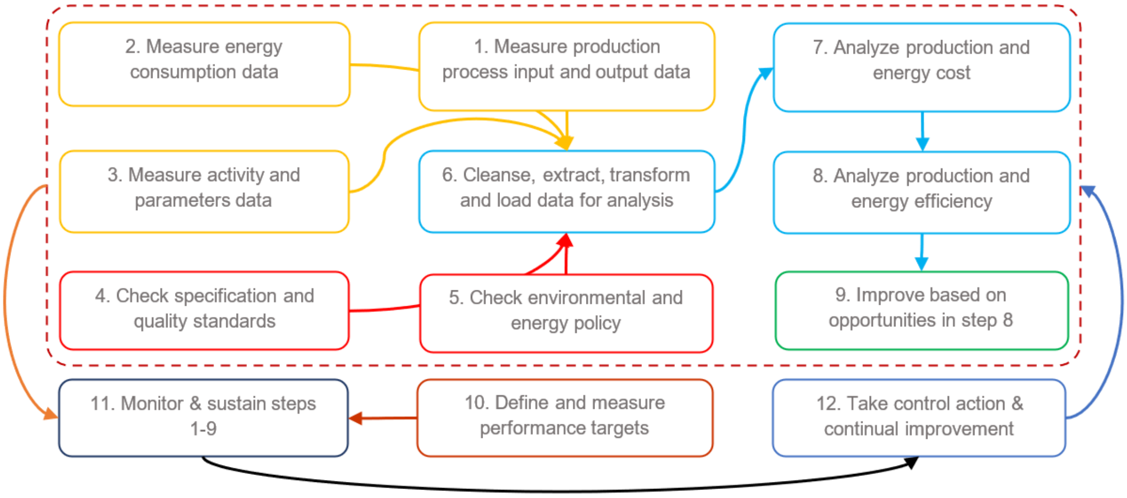

Figure 8. Proposed Conceptual Model of Energy Management in Steel Plant

Table 3. Table of Comparisons

Conceptual model	Real-world condition	The feasible and desirable changes
1) Measure energy consumption data	Energy consumption data are recorded daily. Shop-floor operators documented the meter readings.	Provide and support automated devices and methods by implementing RF technology, networked sensors, and autonomous data mining to capture data.
2) Measure activity and parameters data	Shop-floor operators documented process time and parameters.	Provide and support automated devices and method to capture process data in manufacturing process.
3) Measure production input and output	Shop-floor operators record the volume or length of material processed in each procedure	Provide and support automated devices and methods to capture and store production output data with ERP system, data storage, and data integration tools.
4) Check compliance with standards	Check specification from production orders with product standards.	Compile and propose internal product standards to the national standard board (SNI) via IISIA.
5) Check environmental and energy policy	Complied with related local policy standards but not ISO certified	Compliance with related national policy standards, certified in ISO Energy Management System and Environment Management System, also prepared for future challenges to comply with Paris Agreement terms and UNFCCC declaration terms
6) Check, document, organize, and prepare all data for analysis	Data operators input the written records into a Microsoft Excel spreadsheet.	Provide method and tools to automatically integrate data from different sources, provide a centralized database to be the single source of truth, also prepare data analysis and data visualization tools.
7) Analyze production and energy costs	Engineers analyze data separately, without automated tools. Only the aggregated production cost could be analyzed.	Provide centralized, automated, and standardized way to calculate production costs in different dimensions and time units. Engineers could analyze large amount of data with less time, enabling them to focus more on finding chances of improvement (wastes and variances).
8) Analyze production and energy efficiency	Engineers analyze data separately, without automated tools. Only the aggregated production efficiency could be analyzed.	Provide centralized, automated, and standardized way to calculate production efficiency in different dimensions and time units. Engineers could analyze large amount of data with less time, enabling them to focus more on finding chances of improvement (wastes and variances).
9) Make improvements based on opportunities provided in step 8	Management has difficulty finding the opportunity to save due to insufficient data.	Data sufficiency, engineers capable of handling improvement projects by Lean Six Sigma Green Belt Standards and top management commitment.

CONCLUSION

This study illustrated the soft system approach to develop a conceptual model for energy management in the steel industry, aiming to perceive and systematize the real complex system into an applicable model. This study has been validated and reviewed by representatives from steel industry experts, top management, and policymakers. Simple as it might be, experts concluded that the conclusion could address the ongoing challenges of energy management in the steel industry. However, this study is far from finished. Stage 7 of SSM is not implementable yet due to the required investment and change management, because implementation will need data connectivity and data analytics capability. This study could be improved by implementing the conceptual model into practice, or by widening the scale of study into other industrial sectors

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