2015

Sustainability Index Development for Manufacturing Industry

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Thesis submitted to the Benjamin M. Statler College of Engineering and Mineral Resources at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Science in
Industrial Engineering

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2015

Keywords: Sustainability, Index Methodology, Manufacturing Industry, Carbon Footprint, Energy Efficiency, Sustainable Manufacturing

ABSTRACT

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Manufacturing industries are adopting new techniques and philosophies to address the acute shortage of non-renewable energy. Many of these manufacturing industries are focusing on achieving sustainability in every possible stage of their production, from raw material to the recycling of waste. Thus, the significance of using renewable energy, properly handling waste, and progressively conserving the environment is increasing day by day. In this research, the definition of sustainability is quite specific: being productive while making little to no impact on non-replenishable resources. The objective of the research is to determine the sustainability index of manufacturing plants. Since the topic has a broad scope, this research is limited to small and medium scale industries, which have common sets of operation and defined process plans. Besides, the focus goes into the non-hazardous waste and while doing so the indicators of the index are selected with respect to energy efficiency, workers' health and safety and waste management. An interactive model is prepared to collect the responses. The interactive model has a series of questions that have to be answered. Based on the sustainable index, the model is able to provide suggestions to improve sustainability as well as carbon footprint consumption. The research has used datasets from various projects of Industrial Assessment Center (IAC) at West Virginia University to build the knowledge database. The interactive model system is executed by a software. The software uses the Java® language and is validated by case studies from IAC. The outcome of this research is a software that can immensely help the industries identify their shortcomings in achieving sustainability, determine the carbon footprint reduction potential, and compare the sustainability index among different manufacturing industries.

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Dedication

This is dedicated to my mother Mrs. Umme Habiba Sultana.

Acknowledgements

All praises to God, the most benevolent and the almighty for guiding, blessing and sustaining me through this season of life and especially the successful completion of this thesis.

I would like to take this opportunity to express my heartiest gratitude to thesis supervisor, Dr. Bhaskaran Gopalakrishnan, a professor in the IMSE Department at WVU, for his careful supervision, guidance, valuable suggestions and encouragement throughout this research work.

I would like to acknowledge my profound indebtedness and sincere gratitude to Dr. Kenneth Currie, a professor in the IMSE Department at WVU, and Dr. Ashish Nimbarte, an Associate Professor in the IMSE Department at WVU, for their constant guidance, supervision and helpful suggestions at different stages in conducting this thesis work.

I would also like to acknowledge my sincere gratitude to the Industrial Assessment Center (IAC) for providing the necessary data that facilitated the successful completion of this research work.

Finally, I would like to thank all the faculty and staff of the Department of Industrial and Management Systems Engineering at West Virginia University for their kind help and inspiration.

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1.0 Introduction

It is an age of advanced technology. The development of technology has been such that the world is progressing without due consideration of possible side effects. Industries are booming in an unplanned way and there are numerous ways to rectify it. Since the start of the industrial revolution, industries have been using natural resources. Although it is true that industries are contributing towards the world's economic prosperity, few really know how to measure their growth in a right way. An extensive study[1] by MIT Sloan Management Review found that sustainability will have an impact on how industries think and act. The United States Department of Commerce (DOC) identified sustainable manufacturing as a high priority performance goal. They defined sustainable manufacturing as the "creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound" (DOC 2010). This means that the needs of manufacturers should be balanced against environmental, economic, and social factors as shown in Figure 1.

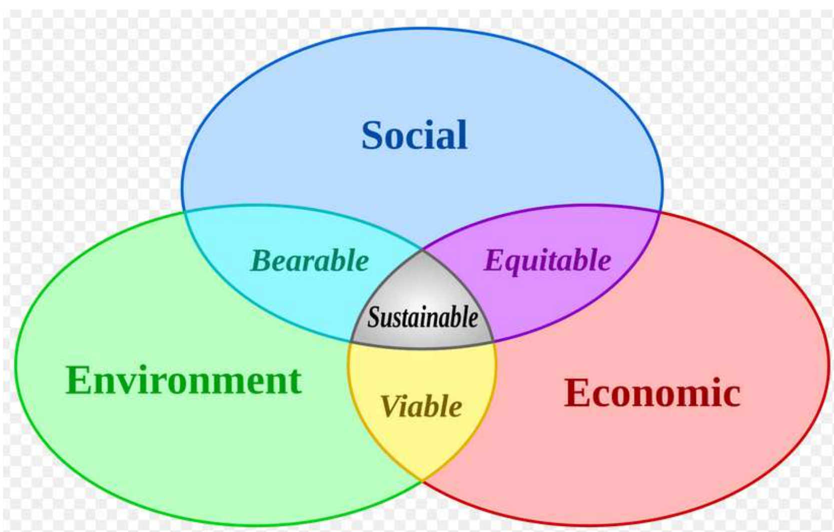

Figure 1: The Triple Bottom Line of Sustainability – Balancing Social, Environmental and Economic Factors (Source: Adams, 2006)

[1] MIT Sloan Management Review. (2010). *The Business of Sustainability* http://www.mitsmr-ezine.com/busofsustainability/2009?pg=5#pg4

1.1 Rationale of the Study

Sustainability in manufacturing has recently received an increasing amount of attention as an effective solution to advance the continuous growth and expansion of the manufacturing industry. So far agricultural systems, ecological systems, and financial institutions have introduced sustainability indices despite having many different approaches applied in various ways without any proper standardization. The manufacturing industry sector has even more anomalies than the previous sectors. Little has currently been done in this field; however, sustainable manufacturing is considered a key step in moving forward. What little work that has been done is unorganized and not enough to properly create a sustainable manufacturing index.

In order to address the performance with respect to sustainability content for a manufacturing process, sustainability metrics must be developed. The ultimate goal of creating such an index is to enhance the decision making capability for changes to manufacturing processes. Current efforts have failed to provide a rigorous index for examining the sustainability of a manufacturing process. To provide a useful tool for comparing sustainability across processes and companies, a comparative and quantitative scoring system must be developed.

Indexing is required in manufacturing fields to evaluate performance and strategize the improvement plan. Sustainable indexing is necessary in manufacturing fields to find where efficiency and productivity can be increased. In addition, sustainable manufacturing can create a positive social impact, which is appraised by the society. It is also important to determine the indicators that affect sustainability of manufacturing industry. The research follows triple bottom of sustainability; hence one indicator from each of the triple sphere has identified. Manufacturing industry uses energy in various sorts of forms. For production, uninterrupted supply of energy is required. So, energy efficiency is a vital part of an industry which can impact the sustainability in various ways. Energy usage needs to be optimized. By ensuring efficient usage of energy, the manufacturing industry can improve the productivity and achieve better sustainability.

Waste management is another aspect from economic sphere of triple bottom of sustainability. Generally, wastes are expensive in a manufacturing industry because they consume production time, raw material, and money. If there is any way to recover or recycle the waste, a manufacturing industry should find a way to do it. Recycling waste can provide better productivity and economic leverage. A manufacturing industry can save carbon footprints by improving the waste recycling capability. The amount of recycled or recovered waste returns back into production and ensure better energy and raw material utilization. Thus, a manufacturing industry can develop more sustainable by managing waste in a better way.

This research has focused on workers' health and safety to contain social sphere of the triple bottom of sustainability. Social sphere has a wide range of factors. Workers' health and safety covers most of the factors from social sphere. The impact of workers' health and safety can consider social happiness, better lifestyle, suitable workplace, and enhanced moral values among society. Therefore, the company can contribute to the society in a positive way and achieve better sustainability.

Thus, a sustainable manufacturing index can quickly enhance the overall quality of manufacturing industries. This framework can be a useful tool for simplifying, quantifying, analyzing and communicating the complex and complicated sustainability information in manufacturing industries.

1.2 Research Objectives

The aim of this research is to develop an interactive model to develop the sustainability index. A low score will indicate an area of shortcoming. Simultaneously, the carbon foot print will be calculated to estimate the amount of energy consumption. This research addresses the problems of overcoming the research gap by synchronizing various indicators. The core focus areas of this research are as follows:

1. Design and development of a standard sustainability index for manufacturing industry.

2. The application of the sustainability index to various manufacturing scenarios to evaluate effectiveness.

3. The examination of the effects of different factors on the Sustainability Index.

4. Development of a carbon footprint measurement to justify the sustainability index.

1.3 Interactive Modeling System

Interactive modeling systems are quite common in recent times the modeling system requires some input from the user. The model has the capability to use the inputs in the calculation for the output. The major difference between conventional and interactive system programs are conventional programs are algorithmic in nature, whereas interactive systems are conceptual in nature and may produce many solutions to a problem with a varying degree of confidence.

There are a number of steps that need to be followed while developing an interactive modeling system. Nagaranjan (1995) described the sequence of steps to ensure easy development and maintenance of the interactive model. The steps are described below:

1. Construct, modify and maintain the domain specific knowledge by scanning through literature and expert opinions.
2. Formalize and create the rule abstractions involving the identification of the logic of the search to be concluded.
3. Evaluate the interactive model containing the programming language, interface modules and interactive programming environments.
4. Design and create the knowledge base rules in accordance with the mechanism of the inference engine.
5. Test, validate and verify the system with reference to its usability, efficiency and cost effectiveness.
6. Integrate graphics into the system to make it more comprehensible and attractive.

The knowledge base consists of production rules developed by the knowledge engineer using the information obtained from the experts and other information sources. The usual components of an interactive system are given in Figure 2.

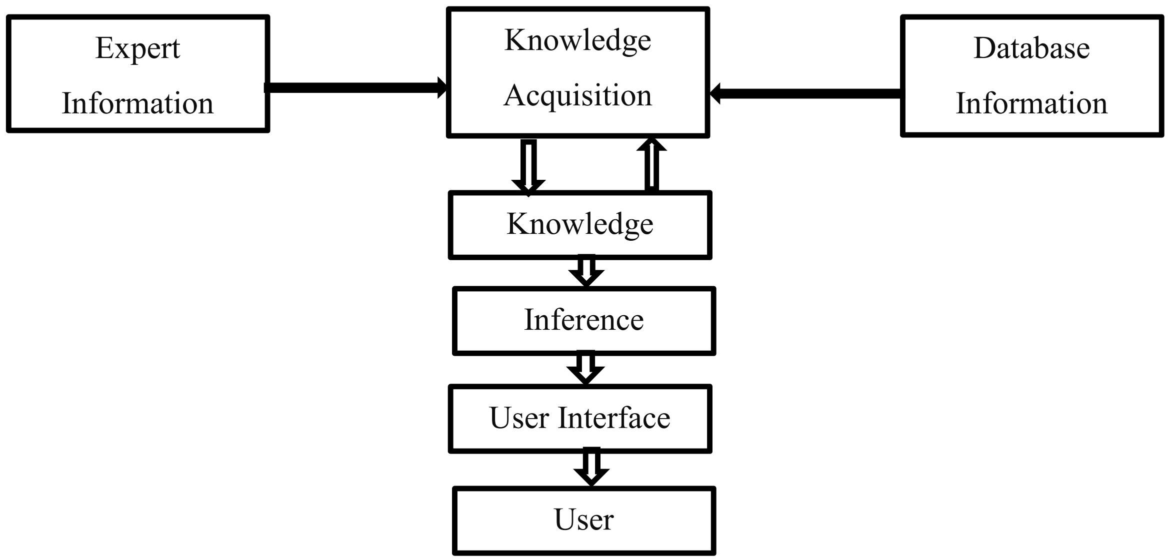

Figure 2: Component of an Interactive Model (Source: Nagarajan, 1995)

In order to develop an expert system, a proper design environment with a set of design tools is necessary. There are a number of interactive model development tools available in the market. Due to availability, portability, and ease of use, Java® is chosen for this task.

1.4 Possible Outcomes of the Study

Sustainability is a popular concept in recent times. This research helps industries to determine their progress towards sustainability. Specifically, it can be a useful tool for the KAIZEN team of an industry. KAIZEN is a Japanese word, which means continuous improvement. Usually a KAIZEN team of a plant determines the possible scopes of improvement and execute the ideas continuously. The core outcome of this research is software which provides a measurement of how well a plant is doing in terms of sustainability. The software is capable to show the area/sector where the company is lagging behind and how they can improve. All these indices and suggestions are given as numeric values so that it is easy to compare and understand.

An interactive model based software is built, through which the sustainability index is calculated. A series of knowledge based inputs from the user will determine relative weightage and calculation method. The adaptable model will be developed to measure the sustainability index of a company. Based on the guideline for an interactive model, a model is generated. The system diagram of the model is given as below:

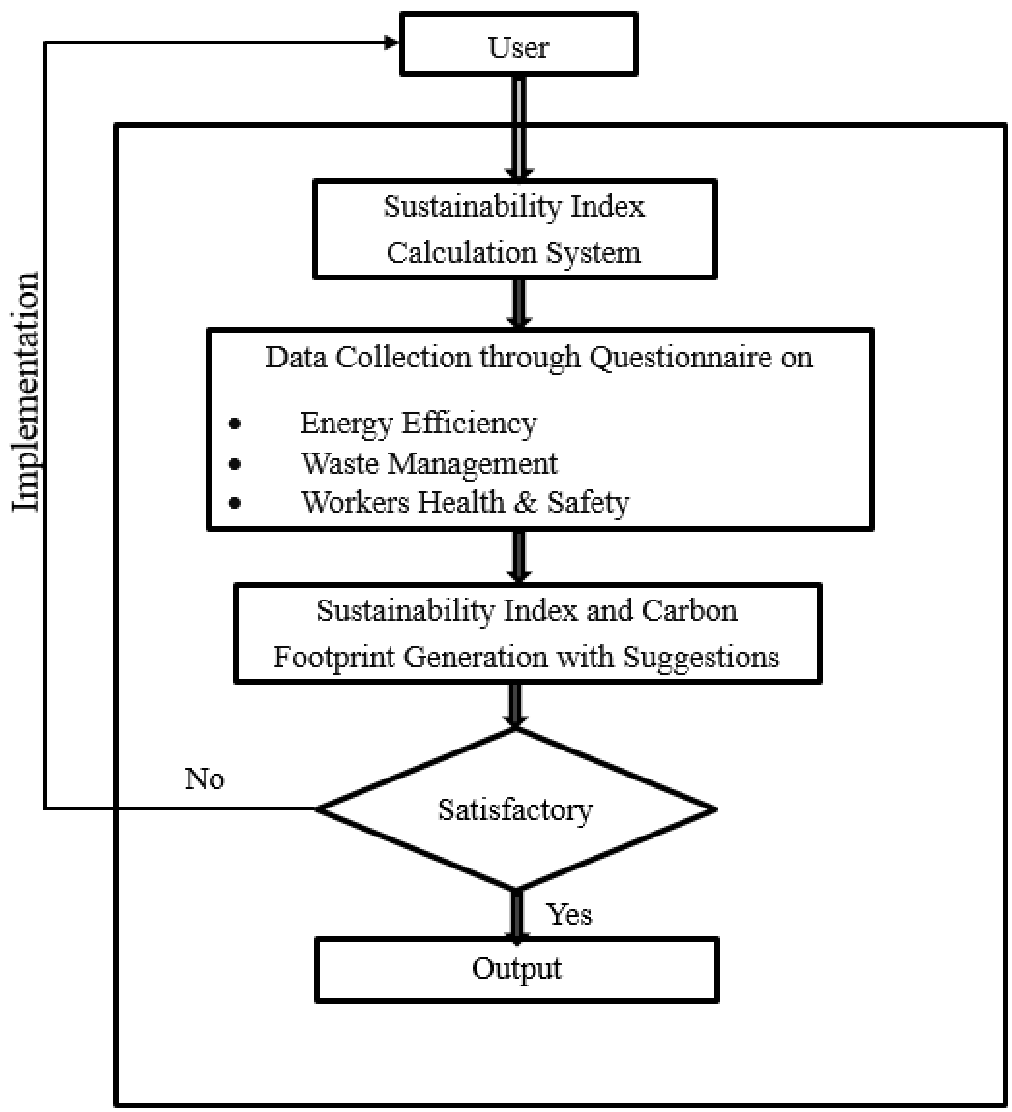

Figure 3: The System Design for Sustainability Index

The unique contributions from the researcher's perspective are discovering the key variables that affect sustainability, accumulating all the alternative solutions of existing systems, creating the algorithm for the sustainability index, setting the benchmark according to the algorithm, and enabling all the information in a user friendly software interface. Finally, sensitivity analysis and validation are executed to ensure the functionality of the algorithm. Two case studies are performed and run through the model. This systematic approach could be useful in sustainable manufacturing practice, if appropriately adopted.

1.5 Limitation of the Study

The study only focuses on both quantitative and qualitative responses. Only positive and negative responses are recorded for the sake of time and simplicity. It would be possible to expand the questionnaire to cover more topics such as those applicable to large scale manufacturing industries; however, this research is solely focused on small to medium scale manufacturing industries.

1.6 Conclusion

This research will help industries determine their progress on sustainability improvement. Specifically, it will be a useful tool for the KAIZEN team of an industry. The core outcome of this research is software that will provide a measure of how well an industry is doing in terms of sustainability. It will also show the areas/sectors where companies are lacking and how they can improve. These ratings and suggestions will be given as numeric values, making them easier to judge and understand.

2.0 Literature Review

Sustainable manufacturing has different meaning to different shareholders. According to the EPA, sustainability is based on a simple principle: Everything that mankind needs for survival and well-being depends, either directly or indirectly, on natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. In summary, sustainability is being productive while making little to no impact on non-replenishable resources.

2.1 Sustainability in Different Sectors

In May 2013, Dow Jones Sustainability Indices (DJSI) in collaboration with RobecoSAM provided a financial sustainability index for investors. Although they are working with a different definition of sustainability, the method of calculating sustainability provides a baseline for calculating diversified indices. They have selected a benchmark from the most sustainable companies while ensuring that the benchmark profile has all the possible sub-indices or criteria. This allows them to calculate the indices for a random company based on their tracking record.

Sustainability index variables differ for every specific project. The methodology of formulating the index should be the prime thing to focus on. Lee and Huang (2007) use 51 sustainability indicators to find out a sustainability index for Taipei, a city of Taiwan. They divide the 51 indicators into 4 different categories such as economic, social, environmental, and institutional dimensions. Zhou et al (2012) discuss how to work with composite indicators while condensing multidimensional indices into one index score. Composite indicators depend on aggregation methods of sub-indices, normalization methods, and a specific weighting scheme. They applied different combinations of dependent variables to find out the best scheme for constructing composite index. The conceptual requirements for a City Sustainability Index (CSI) were discussed by Mori and Christodoulou (2012).

They put importance on creating a CSI and compared different cities' sustainability performances to observe the global impact of cities on the environment and human life compared to their economic contribution. The triple bottom line of the sustainability concept consists of environmental, economic and other social aspects. While calculating sustainability, the researchers must consider the triple bottom line and external impact. Ecological footprint, night time satellite imagery sustainability, emergy/exergy and water footprint show a good capturing capability of external impact. Chavez and Alipaz (2006) created a dynamic and aggregated watershed sustainability index indicator. They integrated hydrologic, environmental, life and policy issues to form their model. They used level indicators for each sub-index and calculated their score based on that. Finally they summarized the overall levels and values for the parameters and analyzed further to make a decision based on that.

A sustainability index should have a proper definition with specific objective. For example, according to Esty et al. (2008), Environmental Performance Index (EPI) focuses on the impacts of countries on the environment, which includes 25 indices with two objectives: (i) reducing environmental stresses to human health and (ii) protecting ecosystems and natural resources. Murty et al (2009) combined all the initiatives and frameworks for sustainable indicators. In the policy practice and formulation strategy determination, the review article gives light to all possible developments in sustainability assessment methodologies. The selection of indicators is very important. Mayer (2008) mentioned the impacts of selecting a wrong set of indicators in his review article. He put a lot of importance on indicator selection and accumulated the current discrepancies in sustainability indices. Another paper by Sands and Podmore (2000) worked on design and development of an Environmental Sustainability Index (ESI) and described a case study used to validate the performance of their index. The EPIC model (Erosion Productivity Impact Calculator) was used and 15 sustainability sub-indices were chosen to determine the index.

Ngai et al. (2012) exposed the intangible benefits of environmental management practices and their potential to drive organizational competitiveness. They also highlighted the fact of a never existing framework for design and implementation of environmental management practice. The authors developed an energy and utility maturity framework for systematic measurement and management of natural resource consumption. They proposed a framework: energy and utility management maturity model (EUMMM). This framework was designed based on the capability maturity model integration (CMMI). A study was conducted to validate the effectiveness, pragmatism and convenience of EUMMM. The five levels of maturity are initial, managed, defined, quantitatively managed and optimized. Four phases of the maturation process are initial to managed phase, managed to defined phase, defined to quantitatively managed phase and quantitatively managed to optimized phase. For EUMMM, Ngai et al. (2012) proposed 4 phases, energy and utility management practice establishment, standardization of energy and utility management practices, strategic environmental performance management and continuous improvement of energy and utility management practices.

Based on the literature, it has been noticed that indicators need to be selected carefully and they should carry significant meaning towards an index. Weightage of the index is also important which can be done in several ways like adaptive weightage system, knowledge based weightage system, expert based weightage system, etc. Further, there should be an appropriate method to aggregate the indicators and provide the index.

2.2 Sustainability in Manufacturing Industry

Nagalingam et al. (2013) measured the performance of product returns with recovery for sustainable manufacturing. They developed a framework for performance measurement with the help of six sigma methodology. Their formulation has 4 phases: a) identifying performance attributes, b) designing performance measurement models on the basis of cost, time and waste, c) optimizing performance measurement model, and d) validating performance measurement models.

A survey of sustainability indices for countries was done by Bohringer and Jochem (2007). The article examined the power of indices on policy making. They scrutinized key requirements to select sustainability indices and came up with requirements, including i) the rigorous connection to the definitions of sustainability, ii) the selection of meaningful indicators representing particular fields, iii) reliability and availability of data for quantification over longer period of time, iv) process oriented indicator selection and v) the possibility of deriving specific objectives. Secondly normalization and weighting needs to be done in a manner that experts' opinions get accounted for. That is where this research may have an impact because it will combine expert opinion and give a preliminary idea about sustainability.

Smith and Ball (2012) described the steps to achieve sustainable manufacturing though modelling material, energy and waste flows. There are a few available principles and guidelines, but these are insufficient. This paper reports on work to develop guidelines for material, energy and waste (MEW) process flow modelling to support the pursuit of sustainable manufacturing. In general they used qualitative MEW flow maps, collected data for a spreadsheet model and performed quantitative analysis to provide detailed insight. They also helped to identify and select environmental efficiency improvements. A case facility has been tried to validate the model. Despeisse et al. (2012) showed that some companies like Brandix, Ford, Sony, and Rolls-Royce are already reaping the benefits of focusing on sustainable manufacturing. A lot of sustainable manufacturing research has focused on product development and end of life management. That means sustainable manufacturing does not provide a methodology for manufacturers to generate improvement within their own facilities.

According to Ball et al. (2008), zero carbon manufacturing (ZCM) can be considered as a constituent element of sustainable manufacturing. ZCM improves the environmental performance of their system by understanding and examining MEW process mapping. A black-box view of the system and its components are adopted and the focus is on examining process inputs and outputs. Carbon reduction programs are always important in achieving sustainable manufacturing.

Some researchers specify that lean approach can be another indicator, even though the notion is not fully supported by all the peers in researching sustainability index in manufacturing plants. Marhani, M.A. et al (2013) discussed how lean approaches can help the cause of achieving sustainability. The manufacturing processes should be assessed using lean manufacturing principles and tools including Value Stream Mapping (VSM), 5S (Sort, Set in Order, Shine, Standardize, Sustain) Workplace Organization, Cellular Flow, Pull/Kanban Systems, and Kaizen events. It is estimated that, with suitable implementation of these lean principles and tools, productivity of a firm could be increased by up to 10% by a reduction in work-in-process time, cycle time, throughput time, lead time, assembly time, material movement and handling time. Therefore, a lean approach by a manufacturing industry could be a good factor for achieving sustainability. Layfield, K. (2013) analyzed how lean approaches can impact a continuous improvement process in a manufacturing industry.

Although it has been assumed that a lean approach is a potential base for sustainable manufacturing and they both are compatible to each other, Yang et al. (2011) shows it is not always certain that lean practice will improve environment performance. This is in spite of the fact that reducing waste and reusing resources across the spectrum of a manufacturing system is mandatory.

Gunasekaran, A. and Spalanzani, A. (2011) overviewed the sustainability of manufacturing and services. The researchers classified and performed a critical review to develop a framework for sustainability business development, and suggested future research directions with tools, techniques and some performance measures and metrics for sustainable business development. The classification scheme for the literature in manufacturing sustainability are i) sources of sustainable challenges and problems, ii) advances in sustainable business development in manufacturing and services, iii) sustainability in product/process design and development, iv) sustainability in supply operations, v) sustainability in production operations, vi) sustainability in distribution chain operations, and vii) sustainability through remanufacturing, recycling and reverse logistics. The article has some future recommendations to select sustainability manufacturing, and they also summarized some of the literature.

Despeisse et al. (2012) discussed sustainable manufacturing tactics and cross functional factory modeling. They focus on the gap in knowledge on how to acquire expected conceptual aims at operational level. A tactic to provide connection between generic sustainability concepts and more specific examples of operational practices for resource efficiency in factories has been presented in the paper. Finally a resource flow analysis is tested and presented via a prototype tool. The overall analysis focuses on the events within the ecosystem of a factory (gate to gate). It accounts for location and time as well as manufacturing process in a manner that is not supported by the independent disciplines of either manufacturing process simulation or building energy analysis tools.

Sustainable Energy Ireland (2009) published a draft of an energy management system which complies with ISO 14001 and is based on the plan of to-do-check-act cycle. Sustainable energy Ireland (SEI)[2] is calling it EN 16001 and it helps organizations set up a comprehensive energy management system and continually improve their utilization performance, leading to lower carbon footprint and lower energy costs. ISO 50001 works in the same direction by establishing the benchmarking energy management framework for industrial plants, commercial facilities and entire organizations.

Some of the latest techniques on sustainable manufacturing has been implemented by Fuzzy based assessment models. Singh et al. (2014) has done a study on fuzzy interference system models for the evaluation of manufacturing sustainability of small and medium enterprises. At first a list of sustainability indicators for manufacturing SMEs is identified and weak areas are being detected to enhance the performance of overall sustainability. Then it will help the strategy maker to select an appropriate strategy to reduce the environmental impact.

Kimura (2012) discussed evolution and the future of sustainable manufacturing. The author advocated a comprehensive framework for resource circulation to improve resource efficiency. System planning and product design technology, manufacturing technology, resource circulation technology are the important research and development items for sustainable manufacturing. In the future, product quality management and innovation, efficiency in manufacturing process, improvement of resource circulation and new product/service for social innovation need to be addressed to progress on sustainable manufacturing.

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[2] http://www.bologna.enea.it/FEM/FILES/picchiolutto-sge/2_Picchiolutto.pdf

Mizuno et al. (2012) approached designing sustainable manufacturing scenarios using a 3S simulator. Here, 3S simulator means sustainable society scenario which is an integrated design support environment for sustainable society scenarios. Scenario represents method, design, analysis and archive. The designing of a scenario involves with setting a problem, constructing a logic tree, determining scenario structure and describing sub scenario. Joung et al. (2012) addressed the need for an improved version of indicator sets, though much work has been done in that field so far. Also, it shows how the indicators can play role to assess a company's manufacturing process from five different dimensions of sustainability: environmental stewardship, economic growth, social happiness, technological advancement, and performance management. Zhai et al. (2012) stated sustainable manufacturing from a pollution prevention standpoint by taking into consideration three key components of manufacturing: technology, energy, and material. They also performed a case study on a nano-manufacturing technology, atomic layer deposition.

2.3 Conclusion

The above literature review gives an idea of the work done in the field of sustainability across different sectors as well as in manufacturing industries. Many issues such as sub-indices, calculation methods, and ideology have been discussed. Minimal work has been found on the methodology for a systematic approach to sustainability with every aspect of manufacturing industries. Most of the research focused on very few factors with a holistic approach, although pragmatic, quantitative analysis is much needed in this area.

3.0 Research Approach

A systematic methodology is required to improve energy efficiency, productivity, and a work environment to achieve sustainable manufacturing goals. For that reason, a sustainability index is an appropriate answer. A sustainability index should be designed in such a way that it becomes applicable to all industries. The index should be chosen carefully so that it truly reflects the sustainability situation of a manufacturing organization, irrespective of any borders. It is very important to find out the correct indicators for a sustainability index so that manufacturing industries can check themselves and identify areas that need improvement. Though some attempts have been made towards developing a sustainability index with some recognized indicators, no attempt has been made to integrate them into a single and comparable number. By making a manufacturing plant more sustainable, its carbon footprint will be reduced, leading to a potential savings. Carbon footprint is defined as the total greenhouse gas emissions caused by an organization, event, product or person[3].

The success and accuracy of a sustainability index depends on how appropriately the given datasets resemble the actual occurrences. To achieve the appropriate resemblance, the index should be properly used in the algorithm. The algorithm should also provide relative sensitivity to the changes in the index's parameter. The most important aspect of the research is to integrate energy, waste and workers' safety into one sustainability index.

3.1 Selection of Sustainability Indicators

Aiming to assess sustainability in manufacturing industries, this research is fully focused on integrating some recognized indicators into one valuable number. Since sustainability is a dynamic and holistic process, it is assumed that a sustainability index is a function of energy efficiency (E), waste management (W), and workers' safety and health environment (H). This research will try to create an algorithm that will consider each of these indicators

[3] http://en.wikipedia.org/wiki/Carbon_footprint

and provide a single number to compare among small to medium scale manufacturing industries.

As all the indicators that influence sustainability of a manufacturing industry are not measurable and corresponding data collection of all parameters often becomes difficult, it is not possible to include all the variables in the model. Considering the influence of indicators on sustainability, specifically in the environment of small to medium scale manufacturing industries and depending on the availability of related data, three indicators have been selected as the input parameters to model the sustainability index structure. The selected parameters with rationale for their selection are given below.

1. Energy Efficiency (E): Energy efficiency is the first and foremost indicator of sustainability prediction. The National Association of Manufacturers (NAM, 2010)[4] stated that the manufacturing sector consumes around one third (33%) of all energy in United States. It is obvious that energy plays a big role in any kind of manufacturing industry. A company or organization's sustainability largely depends on how efficiently it is using energy. In many cases, the energy efficient mode is a lucrative upfront approach that pays for itself over time, while providing the extra benefits of minimizing energy cost and maximizing energy productivity. Interest in energy efficiency is not a new idea. Afgan, N.H. et Al. (2000) has discussed how energy system assessment is an important indicator of sustainability. Indeed, the growing adoption of energy saving techniques is a recent trend in manufacturing industries. From the Industrial Assessment Center (IAC) database, the sub-indices or questions, have been prepared. There is a software called 'Energex' that has been used widely to estimate the efficiency of energy. Energex was created by Gopalakrishnan, B. et al. (1997) for the US Department of Energy. By adapting the Energex software and using the IAC database, 29 factors have been selected from 8 sub-groups that affect the efficient usage of energy. The 8 sub factors are lights, HVAC, steam, process heat, pumps and fans, motors, air compressors, and cooling towers or chillers.

[4] http://www.nam.org/Newsroom/Facts-About-Manufacturing/

2. Waste Management (W): Mayer A.L. (2008) discussed the strengths and weaknesses of a sustainability index. One of the important guideline for achieving better sustainability is following the triple bottom line of sustainability. Waste management falls into the environmental aspects of sustainability. Managing waste is one of the most effective ways to achieve sustainable manufacturing processes. Manufacturing industries are confronted with several challenges, such as energy and water efficiency, environmental emissions, carbon footprint issues, and lost workdays due to workers' injury and illness issues. All these factors collectively add waste to the production of goods, significantly impacting the bottom line and future growth of these industrial facilities. Mangalampalli (1997) created software called 'Wastex' which deals with waste minimization. This research has used Wastex features and factors to estimate waste minimization performance. Only solid waste has been taken into account for this research. Fifteen factors will be used to calculate a sustainable manufacturing index. There are nine types of waste. Each types of waste is forming each factor. The general approach concerning to waste are forming another six factors. These general approaches are focusing on general strategy of handling waste for a particular plant. Six general approach factors are companywide initiative, proper guidelines for electronic waste disposal, labelling and storing of harmful substances, reinforcement on recycling, trash picking program, and single stream implementation.

3. Workers' health and Safety (S): If workstations are not designed ergonomically, they increase the risk of acute as well as chronic injuries. Most of the non-ergonomically designed workstations or tasks have at least one human factors issue. According to Young (2009), simple design suggestions based on the ergonomics interventions are known to eliminate or reduce possible risks for workplace accident or injuries. Further, Monden, Y. (1986) revealed that improved workstations and tasks have a positive effect on workers' health and overall attitude. Based on these findings, it is apparent that sustainability depends on workers' health and safety. It also falls into the category of social for triple bottom

line of sustainability. Since the cost of injuries and accidents due to human factors issues varies significantly, sustainable manufacturing must have consideration for workers' health and safety. National Institute for Occupational Safety and Health (NIOSH) uses a standard questionnaire to assess a workplace environment. This research has used the germane parts of that questionnaire and adapted it into 33 factors with four sub-groups to figure out the sustainability impact of a manufacturing industry. The four subgroups are physical exposure, psychosocial and psychophysical exposure, environmental exposure, and general policy. Working methods differ among industries. There should be a method to address different focuses and needs for different industries so that particular subgroups can get proper attention.

All the parameters and outcomes are shown in Table 1.

Table 1: Indicators and Parameters of Sustainability Index

Indicators	**Details**	**Source**	**Structure**
Energy Efficiency (E)	Measuring the energy efficiency approach	Energex IAC Database	29 Factors 8 Sub-groups
Waste Management (W)	Finding out the waste management attitude	Wastex	15 Factors
Workers Health & Safety (H)	Workers health and safety environment	NIOSH	33 factors 4 Sub-groups

3.2 Weightage and Aggregation Technique

A questionnaire containing all the indicators, subgroups, and factors is prepared. Users can answer the questions. The questionnaire is designed in such a way that positive answers represent better sustainable approaches and negative answers represent bad sustainable approaches. For example, in the energy efficiency index section, there is a subgroup called Compressed Air. The questionnaire has 5 factors, or 5 questions in this section. Users will respond to the 5 questions with "Yes," "No," or "Not Applicable."

After collecting the responses from the users, it is very critical to integrate the responses in a proper way. "Yes" responses are recorded as positive responses and "No" responses are recorded as negative responses. "Not Applicable" responses are eliminated from further calculation. Performance indicator is simply the ratio of the positive responses to the total number of responses.

Performance Indicator,

$$Q_i = \frac{\text{Number of Positive Responses}}{\text{Number of Positve Responses + Number of Negative Responses}} \% \quad (1)$$

Performance indicator reflects the sustainable approach of that subgroup. Better sustainable approaches can provide higher positive responses. They lead to the plant getting a higher performance indicator. Because of the diverse nature of the individual sustainability indicators, the physical measurement of individual metrics cannot be directly aggregated. All the indicators need to be converted to a single normalized scale. In this research methodology, all the individual indicators are normalized to a single scale from 0 to 100%, where 0 is the worst sustainability performance and 100% is the best sustainability performance.

From the literature review, it has been found that there are several ways to do approach this challenge, but these approaches have to consider all aspects, such as counting relative boundary limit, comparison across indices, etc. Without prior information, the weightage can be placed by matching percentile methodology in indices. Foa, R. (2012) has shown the appropriateness of using matching percentile methodology when some data are imputed. In the questionnaire there are "Not Applicable" responses. In that case, matching percentile methodology drops those responses. For instance, if a subgroup gets all not applicable responses, it will not take part into any further calculation. If a subgroup gets all negative responses, it will provide performance indicator as 0%.

Determining the relative importance or impact levels on overall sustainability index is another challenge. Another widely used technique in this research is using pairwise comparison. The NASA Task Load Index (TLX), prepared by the Human Performance Research Group, California (1988) has used this pairwise technique effectively and exhibited how this technique is very useful in calculating index. Pairwise comparison is a method where each candidate is matched with each of the other candidates. Based on the user selection, each candidate gets prioritized. In this research, the pairwise comparison technique has been applied to figure out relative weightage among different categories. At subgroup levels of workers' health and safety, it has been applied, and relative weightage among different subgroups is determined. To determine the relative weightage among energy efficiency index, waste management index and workers' health and safety index, the pairwise comparison technique proves to be very useful.

The weightage of the indicators are set from the calculation of the selections from the pairwise technique. The rationale behind choosing this method is to apply relative importance with respect to the individual organization's setup. Every manufacturing plant is unique. At the same time, the manufacturing industries have some common basic traits that can be counted. A sustainability index should focus on those areas. Even though there are common traits, these traits' levels of importance vary from industry to industry. Some of those levels are intentionally ignored, whereas some of those levels of common traits are out of scope. For example, a metal manufacturing industry will certainly generate more waste than an industry producing spark plugs. Hence, there is a high chance that the metal manufacturing industry will focus more on waste management, whereas the spark plug industry will focus more on a lean approach. Both industries should have a common approach towards energy efficiency and workers' health and safety. Based on their focus and need, the weightage on each indicator will be changed according to the response, thereby providing the adaptive weightage approach towards the sustainability index.

3.3 Modeling the Sustainability Index

Although it is recognized that the sustainability practices of manufacturing industries are directly related to energy efficiency, waste management policies and workers' safety, few attempts have been made to integrate these factors into one meaningful and comparable number. Varying from 0 to 100, a sustainability index can be simple to use, robust and applied worldwide to assess manufacturing industries. Before determining the overall sustainability index, three indicator indexes needs to be calculated. The methods used to calculate each indicators' index are discussed in the following section.

3.3.1 Energy Efficiency Index: In the energy efficiency sector, consumption-based relative weightage has been placed to acclimatize different systems of manufacturing plants. Energy consumption profiles vary among industries; therefore, energy usage needs that adaptation capability to provide a meaningful sustainable index. The input and output parameters are given as below.

Table 2: Input and Output Parameters for Energy Efficiency Index

Input Parameters	Output Parameters
Energy distribution profile (Total annual energy consumption for electricity in kWh/yr & fuel in MMBtu/yr, and consumption percentage distribution of subgroups by ePEP[5] analysis)	Consumption percentage
Response of the questionnaire	Performance indicator
Number of implemented projects in last 5 years	Carbon footprint reduction potential

The software takes the consumption percentage from each user and uses the weighted average to acquire a 100% ratio. Later on, performance Q_i is multiplied by the relative weightage average to capture the overall impact of each group. In this way, energy efficiency reflects the real situation of that particular industry.

In this research, all three sections of energy efficiency, waste management and workers' health and safety have used this performance indicator in different levels. Figure 4 shows the calculation method of performance indicator for subgroup "Compressed Air."

1.7 Compressed Air

- Do you have air leaks survey routine for your pressure line?
  Yes / No/ Not Applicable
- Do you use vortex nozzle for cleaning?
  Yes / No/ **Not Applicable**
- Do you use sequencer for compressors, if you have multiple main compressors?
  Yes / No/ **Not Applicable**
- Do you recover the heat from the compressor?
  Yes / No/ Not Applicable
- Are the compressors running at the lowest possible set pressure?
  Yes / **No**/ Not Applicable

The user provides 2 positive responses, 1 negative response and 2 not applicable responses, so the performance indicator Q_i is 2/ (2+1) = 2/3 = 67%

Figure 4: Sample Calculation for Performance Indicator, Q_i

[5] https://ecenter.ee.doe.gov/EM/tools/Pages/ePEP.aspx

For the energy efficiency section, there are 29 factors in 8 subgroups. The user is required to provide an approximate energy consumption percentage with respect to each of those 8 sub-groups. Using a software called ePEP[6] designed and provided by the Department of Energy (DOE), the user can estimate energy consumption percentage based on energy bills and usage of the equipment.

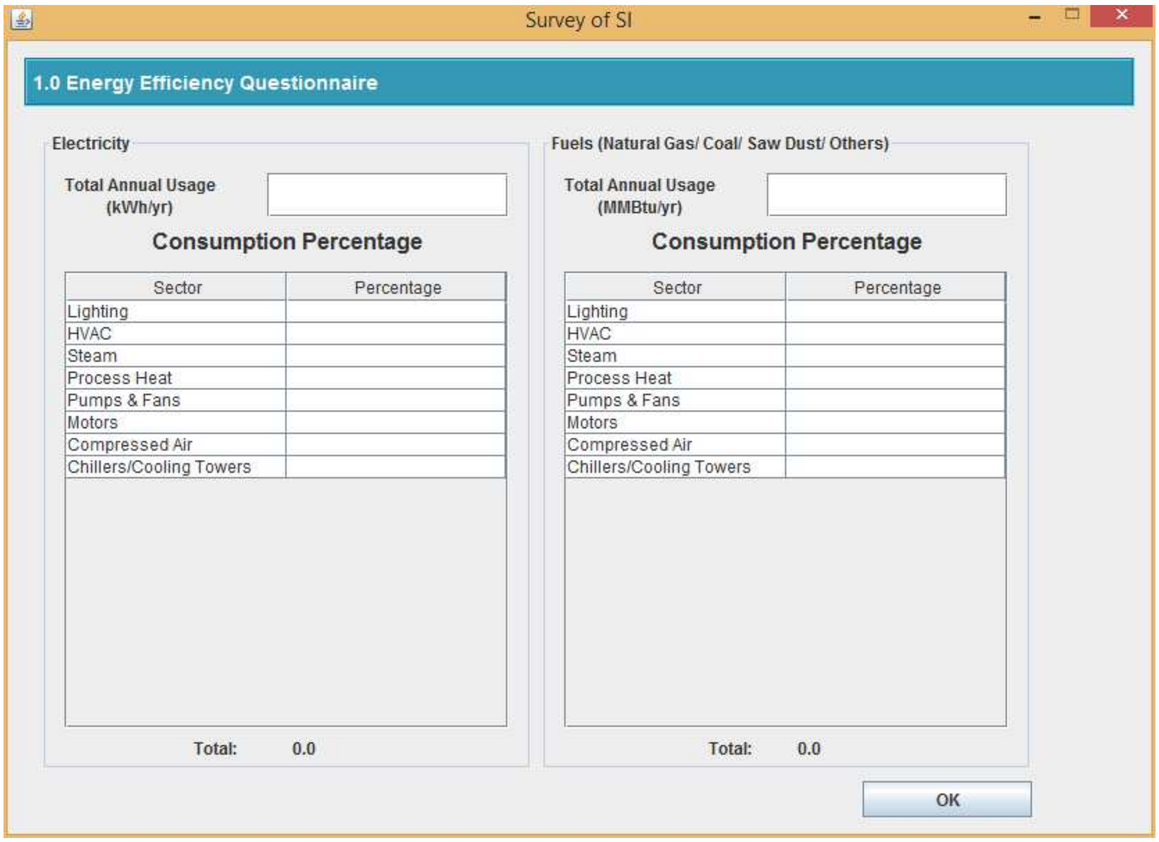


Figure 5: Consumption Percentages for Electricity and Fuel (natural gas/coals/saw dust/ others)

The model necessitates consumption percentage with respect to electricity and fuel (natural gas/coals/saw dust). Moreover, the model needs the total annual consumption usage for electricity (kWh/yr) and fuel (natural gas/coal/sawdust/ others) (MMBtu/hr). Total annual consumption is required to calculate carbon footprint reduction potential. The model records the responses of 29 factors from 8 groups. Consumption percentages are given for each subgroup with respect to electricity and fuel. From this information, the total

[6] https://ecenter.ee.doe.gov/EM/tools/Pages/ePEP.aspx

consumption of energy usage by each group can be determined. The equation of usage for each subgroup is as follows

$$\text{Usage of subgroup i, } M_i = \frac{x_{ie}\frac{a_e}{293} + x_{ig}a_g}{\frac{a_e}{293} + a_g}\% \tag{2}$$

Here, i = 1, 2, …, 8 whereas i_1 = Lighting, i_2 = HVAC, …, i_8 = Chillers/Cooling Towers

X_{ie} = Electricity consumption percentage of i subgroup

X_{ig} = Fuel (natural gas/coals/sawdust/others) consumption percentage of i subgroup

a_e = Total annual electricity consumption, kWh/yr

a_g = Total annual fuel (natural gas/coal/sawdust/others) consumption, MMBtu/yr

293 is the constant which comes from 1 MMBtu = 293 kWh

From equation (2), the total consumption of a particular subgroup can be calculated. These calculations will eventually serve as relative weightage (M_i).

Figure 5 shows the table where users deliver the consumption percentages. From users' provided percentage data, overall consumption percentage of the subgroup is determined. From Figure 4, the performance indicator Q_i is found as 67%. If the total annual electricity usage a_e is 2,930,000 kWh/yr and total fuel (natural gas/coal/sawdust) consumption a_g is 10,000 MMBtu, total energy consumption is (2,930,000/293 + 10,000) = 20,000 kWh/yr. Overall consumption percentage is used as relative weightage, M_i. If electricity consumption percentage of compressed air X_{ie} is 15% and fuel (natural gas/coals/saw dust/others) consumption percentage of compressed air X_{ig} is 0%, overall consumption percentage of compressed air stands as

$$\frac{0.15\times\frac{2,930,000}{293} + 0\times 10,000}{\frac{2,930,000}{293} + 10,000}\% = 7.5\%$$

The energy efficiency index is the multiplication of relative weightage (M_i) and performance (Q_i) from equation (1).

$$\text{Energy efficiency index} = \sum (M_i \text{ x } Q_i) \text{ x } 100 \text{ ; } i = 1, 2, \ldots, 8 \quad (3)$$

Here,

M_i = Relative weightage of group i

Q_i = Performance of group i

The carbon footprint reduction potential for the energy efficiency section is described below.

$$\text{Carbon Footprint Reduction Potential} = [\sum_{i=1}^{8} \{(1-Q_i)\times x_{ie}\}\times a_e \times 2.19\times P] + [\sum_{i=1}^{8} \{(1-Q_i)\times x_{ig}\}\times a_g \times 139\times P] \text{ lbs} \quad (4)$$

Here,

Q_i = Performance of group i

X_{ie} = Consumption percentage of electricity of i group

a_e = Total annual electricity consumption, kWh/yr

2.19 is used as constant since 1 kWh = 2.19 lbs CO_2

P = Constant, based on number of implemented project, k where

$$P = \begin{cases} 0.15 & \text{when } k < 5 \\ 0.10 & \text{when } 5 \le k \le 10 \\ 0.05 & \text{when } k > 10 \end{cases}$$

X_{ig} = Consumption percentage of fuel (natural gas/coals/saw dust) of i group

a_g = Total annual fuel (natural gas/coals/saw dust) consumption, MMBtu/yr

139 is used as a constant since 1 MMBtu = 139 lbs CO_2

From the above equation (4), carbon footprint reduction potential can also be achieved by being more sustainable in using energy. In the equation (4), value of P is .05 when number of implemented project in last 5 years is more than 10. It indicates the capability of the plant's carbon footprint reduction, which is only 5% in this case. Since the plant implemented more than 10 projects, it is unlikely to save a lot of carbon footprint in this plant. Thus, the plant gets only 5% potential savings. Similarly, if the plant implements 5 to 10 projects in last 5 years, the potential carbon footprint savings constant is 10%. Again, 15% carbon footprint savings come from less than 5 implemented projects in last 5 years. This opportunity can demonstrate how much carbon exhaustion is saved by embracing a sustainable approach.

3.3.2 Waste Management Index: For the waste management segment, there are 15 factors without any subgroup. Industries generate various kinds of waste, making it time consuming for users to respond to groups of nonrelated waste questions on the questionnaire. To make it effective and compact, all 15 questionnaires are arranged without any subgroup.

Table 3: Input and Output Parameters for Waste Management Index

Input Parameters	**Output Parameters**
Response of the questionnaire	Performance indicator
Waste generation amount in tons/yr with recycle percentage	Carbon footprint reduction potential

The user is required to provide an approximate tonnage of waste generation per year and a recycling percentage. Figure 6 depicts nine types of generated waste. In *Energy Analysis of 108 Industrial Processes*, Harry Brown (1996) analyzed the carbon footprint of different raw materials and wastages. After collecting data from that book and the Wastex software, it has been perceived that manufacturing industries are generating nine types of waste. The model does not provide any relative weightage among the waste; rather, it focuses on the plant's approach to deal with the waste. Users provide recycling percentages from which the aggregated recycling percentage can be determined from the following equation.

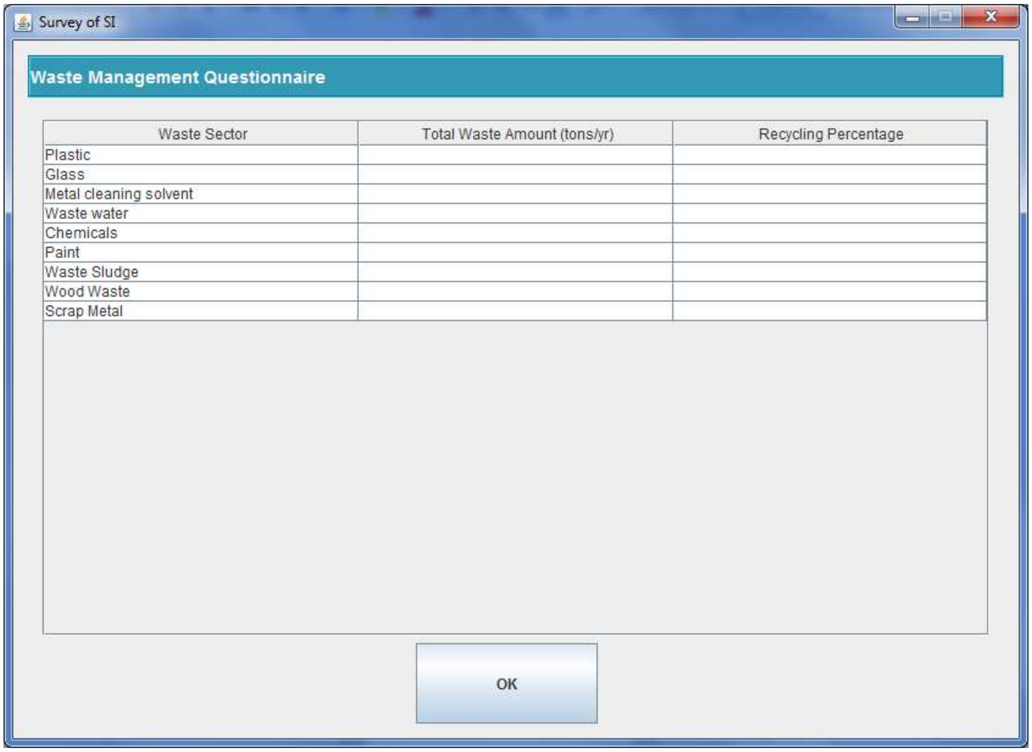


Figure 6: Generated Waste Amount and Recycling Percentages

$$\text{Aggregated Recycling Percentage, } G = \frac{\sum_{i=1}^{9} R_i t_i}{\sum_{i=1}^{9} t_i} \% \;\; ; i = 1, 2, .., 9 \qquad (5)$$

Here, i_1 = Plastic, i_2 = Glass, …, i_9 = Scrap Metal;

R_j = Recycle percentage of waste group i

t_j = Total waste amount of group i, tons/yr

Performance indicator Q_i is vital in a waste management index. It is the same as the energy efficiency performance factor mentioned in equation (1).

$$\text{Waste Management Index} = (G \times Q_i) \times 100 \qquad (6)$$

Here, a "Not Applicable" response means this kind of wastage is not being generated by the particular manufacturing plant, so it is ruled out from any further calculation. To improve the waste management index, the manufacturing industry has to focus on its waste handling technique. If a plant has a high recycling percentage with better waste management approaches, a higher waste management index can be achieved.

For the carbon footprint reduction, a company should have the capability to recycle 100% of their generated waste. While this is very challenging, companies must try to achieve that target, as it can immensely reduce the carbon potential. In fact, better waste management approaches reduce more carbon footprint than efficient energy usage does.

The carbon footprint reduction potential for the waste management section is described below.

$$\text{Carbon Footprint Reduction Potential} = \sum_{j=1}^{9} \{(1-R_j)\times t_j \times Y_j\} \text{ lbs} \quad (7)$$

Here, j = 1, 2, …, 9

R_j = Recycle percentage of waste

t_j = Total waste amount, tons/yr

Y_j = Constant which varies with each type of waste, lbs/ton

The values of Y_j with respect to different wastes are given in the following Table 4.

Table 4: Carbon Footprint Value, Y_j with respect to Waste Type

Type of Waste	Carbon Footprint (lbs/ton)
Plastic	2,300
Glass	2,004
Metal Cleaning Solvent	113
Waste Water	700
Chemicals	3,400
Paint	400
Waste Sludge	19,510
Wood Waste	570
Scrap Metal	9,200

From the above equation (7), carbon footprint reduction potential can also be achieved by being more sustainable in recycling waste. This opportunity demonstrates how much carbon exhaustion is saved by embracing better waste management approaches.

3.3.3 Workers' Health and Safety Index: Even though there are similarities among manufacturing industries, each type of industry runs in different ways. Workers' duties and responsibilities change based on the practice of the industry. An automated manufacturing industry, for example, is quite different from a physical labor dominated industry. Moreover, there are many industries in which cognitive part is the dominant section for workers. After analyzing several industry records from NIOSH and the E3 projects of West Virginia University, it has been found that four major areas are contributing profoundly towards workers' health and safety in a working place. These four major areas are physical exposure, psychosocial and psychophysical exposure, environmental exposure and general policy. Thirty three factors as well as 33 questions in total have been designed for the workers' health and safety index within 4 subgroups.

Table 5: Input and Output Parameters for Workers' Health & Safety Index

Input Parameters	Output Parameters
Pairwise comparison among 4 subgroups	Relative weightage
Response of the questionnaire	Performance indicator

The pairwise comparison technique discussed earlier has been used here to figure out the relative weightage of each subgroup. The user has to choose one of two available candidates, and based on the selection, the relative weightage will been determined. In spite of using the same technique for top level relative weightage calculation, this method varied a little in this situation since there are many possible outcomes. In total, 6 selections can get recorded and each candidate can get any number of selections ranging from 0 to 3; thus, the selections become difficult to keep track of and analyze on the basis of situation. Another normalization technique has been applied based on the recorded responses, showing the impending relative weightage as a percentage from the ratio of recorded selections and total number of selections. Equation (8) shows the normalization technique on the selection.

Relative weightage for the subgroups of workers' health and safety index,

$$U_i = \frac{\text{Number of Selections for Subgroup i}}{\text{Total Number of Selections}} \quad (8)$$

Here, i = 1,2,3,4 and total number of selections = 6

i_1 = Physical posture, i_2 = Psychosocial and psychophysical exposure, i_3 = Environmental exposure, i_4 = General policy

Again, performance indicator Q_i is vital in a waste management index. It is the same as the energy efficiency performance factor as mentioned in equation (1).

The workers' health and safety index is the multiplication of relative weightage (U_i) and performance (Q_i).

$$\text{Workers' Health \& Safety Index} = U_i \times Q_i \qquad (9)$$

Here, i = 1, 2, 3, 4

U_i = Relative weightage of group i

Q_i = Performance of group i

For workers' health and safety, carbon footprint is not directly connected to the index, but it affects productivity; hence, more sustainable working conditions can reduce carbon footprint. However, this research is not focusing on this factor due to this factor's low impact on the carbon footprint reduction potential.

3.3.4 Overall Sustainability Index: Overall Sustainability Index (SI) for manufacturing industries will be obtained by the following equation:

$$SI = \frac{\sum_{i=1}^{3} Z_i a_i}{\sum_{i=1}^{3} Z_i} \quad ; i = 1, 2, 3 \qquad (10)$$

Where SI (0-100) is the sustainability manufacturing index

a_i = Individual index on each indicator = Any values from 0 to 100

Z_i = Weightage on each factor

a_1 (0-100) is the energy efficiency indicator; a_2 (0-100) is the waste management indicator; and a_3 (0-100) is the workers' health and safety indicator. Weightage on each factor is calculated using the pairwise comparison technique. The user has to choose one of two available candidates, and based on their selection, relative weightage will be determined. There are only two situations that may occur: each candidate gets the same amount of selection, or each candidate gets a different amount of selection ranging from 0 to 2. The following table shows the two possible situations and relative weightage according to the scenario.

Table 6: Relative Weightage with Possible Different Scenarios

Candidates (Energy Efficiency, Waste Management, Workers Health & Safety)	Situation 1		Situation 2	
	Recorded Response	Relative Weightage, Z_i	Recorded Response	Relative Weightage, Z_i
Candidate one	2	50%	1	33.33%
Candidate two	1	30%	1	33.33%
Candidate three	0	20%	1	33.33%

The relative weightage for situation 2 is quite simple and clear. For situation 1, candidate three with zero responses should not be totally ruled out because its impact on sustainability index cannot be completely oppressed. Thus, candidate one is getting more importance while candidates two and three also have significant importance on the sustainable index situations. The relative weightage distribution is justified by case studies in later stages.

The sustainability manufacturing index is simply the weighted average of three indicators (E, W, S). As per Equation (10), the indicators have been assigned with the relative weightage, Z_i. In the event of a situation in which indicators' weights might vary from plant to plant, weights should be selected by consensus among several stakeholders of the company. Using the adaptive weight helps to avoid the skewing of results, and allows for mutual respect among different companies and stakeholders. Furthermore, the linear and weighted average structure of equation 10 is simple and transparent, allowing for error compensation in the indicators and parameters.

From the recorded responses of the questions and pairwise comparison, the score for individual indicators is calculated from a database. It can also point out the sector where the company is really lacking in sustainability. Thus, a sustainability index can help give the user an idea about how their industry is doing on sustainability. It will help the company to improve its overall scope and sustainability.

3.4 Conclusion

The research methodology strictly tries to follow the previous literature. It has integrated all the factors in a unique way. The main challenge of this particular study is to combine all the factors in such a way so that the index represents the proper situation of a manufacturing industry. With incorporating an adaptive weightage system and standardization, the index is well generated. With carbon footprint reduction potential calculation, it can really help society as well as manufacturing industries.

4.0 The System Design

The interactive model software helps to identify various sustainability-oriented manufacturing processes. The expert system has diagnostic aspects and operational details. It was developed using object-oriented Java®.

The Java® language is a very user friendly language for writing an object-oriented program. It runs in Java® supported computers regardless of operating system. In this research, software has been developed using Java® to quickly calculate a sustainability index and take additional measures. The graphical view of the system is shown below.

The decision to use Java® compatible software is to enhance the portability of the project. It is available to use on any computer system, so everyone in the plant can ask questions and receive feedback on a company's sustainability index. The software is very user friendly, so it can be used by any worker in the plant.

4.1 Data Collection

Based on the questionnaire in the appendix, this software asks the user questions. The software also asks for some assumptions and responses for some options. The process structure, flow, sub-process relationships, and associated data need to be clearly understood. Furthermore, the objectives, metrics, constraints, and control variables need to be identified. The model can then be expressed using aforementioned data and computed expression.

The following flowchart in figure 7 shows step by step development of the system software.

Figure 8 shows how the software asks, records, and prioritizes responses from the user. Based on the responses, the software calculates relative weightage (Z_i), or importance of the indicators for that specific manufacturing industry.

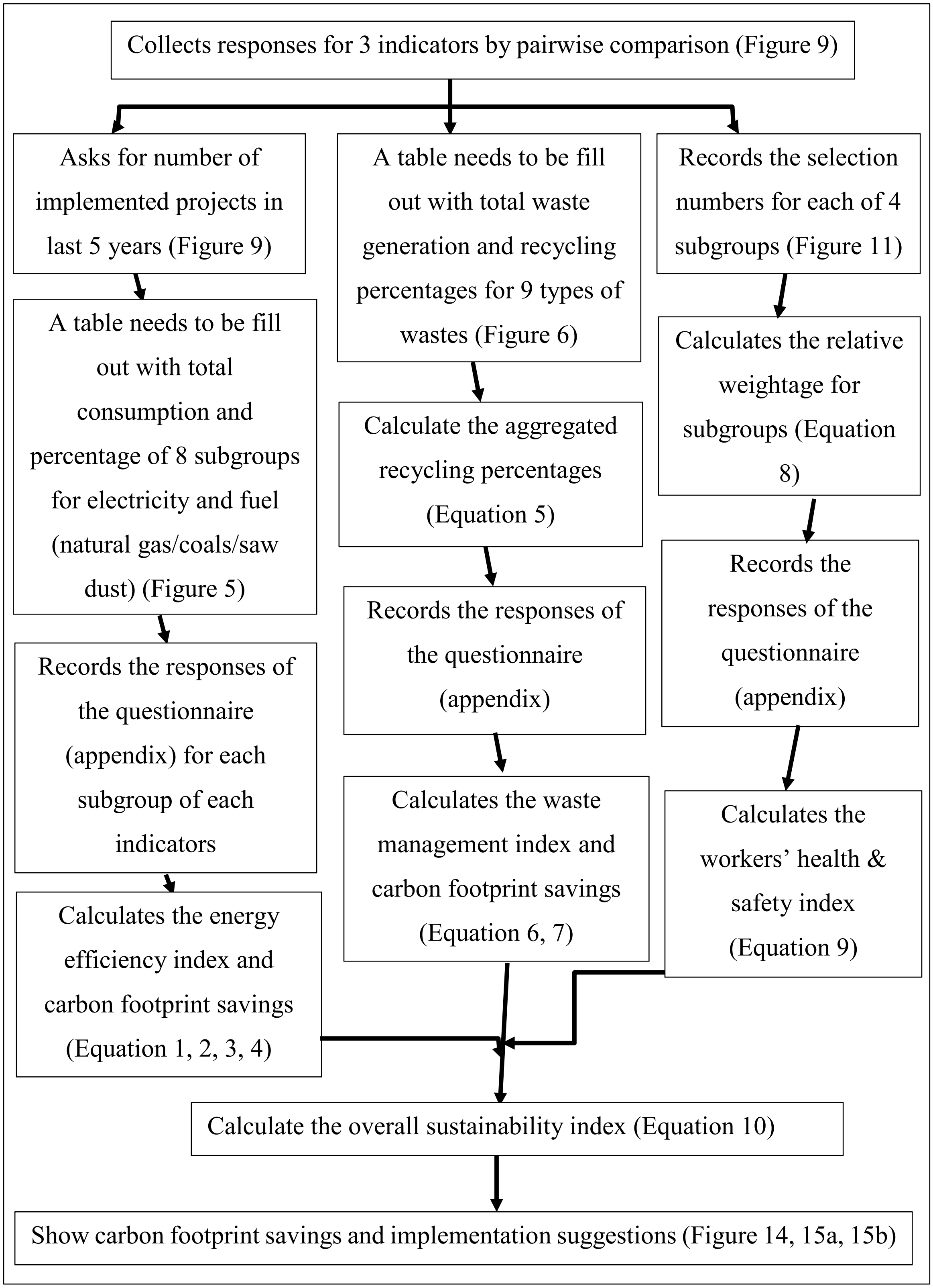


Figure 7: Algorithm for Interactive Model Software

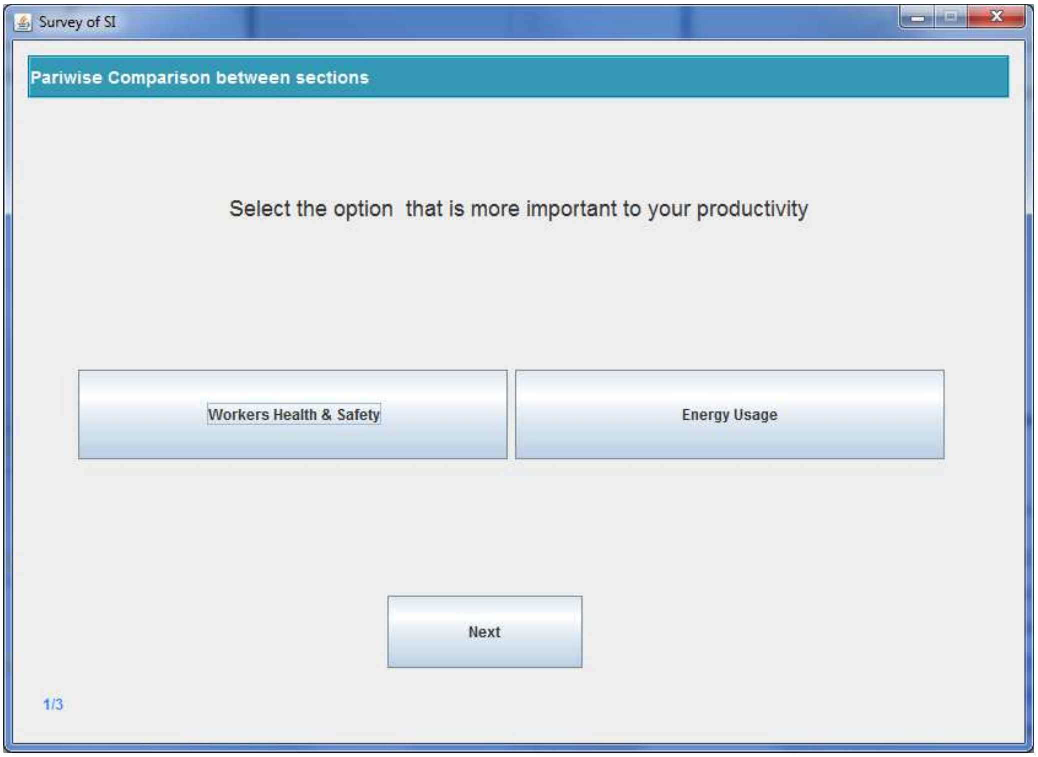


Figure 8: Seeking Responses from the User

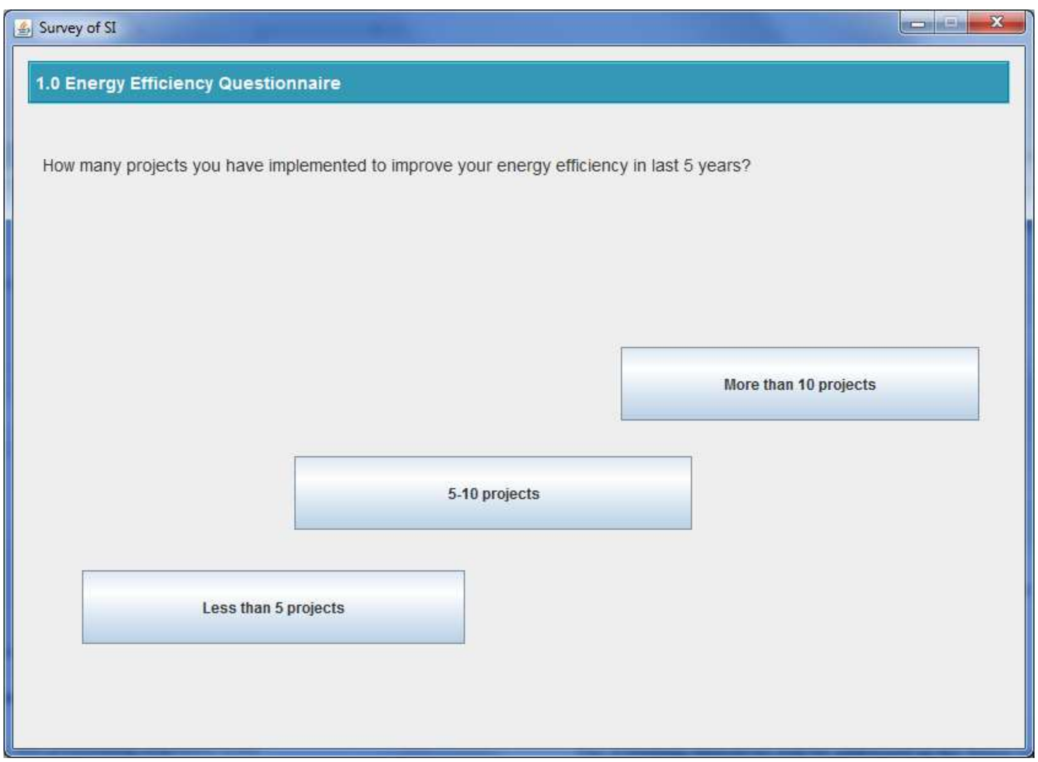


Figure 9: Recording the Response to Calculate P of Eq. (5)

Figure 9 illustrates how the model collects responses from questionnaire and calculates the value of parameter P. Figures 6 and 7 exemplify the numeric data collection procedure which will later help to calculate carbon footprint reduction potential for the energy efficiency index and the waste management index. These numeric data also help to identify relative weightage (M_i) among subgroups of the energy efficiency section.

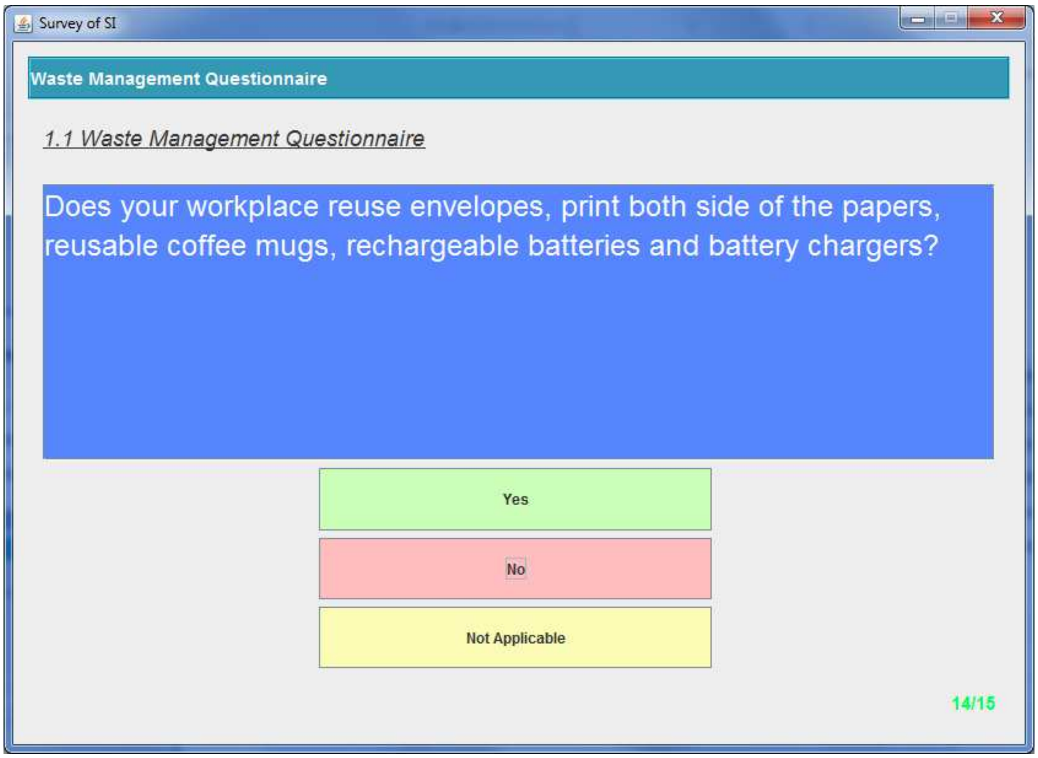


Figure 10: Collecting the Responses to Originate Performance, Q_i

The software asks all the questions, and the model calculates all the required performance indicators. Figure 10 shows the method of response collection. For all three individual indicators sustainability index, these responses provide performance of subgroup i.

Figure 11 also demonstrates the method of collecting responses and adapting the relative weightage (U_i) based on responses.

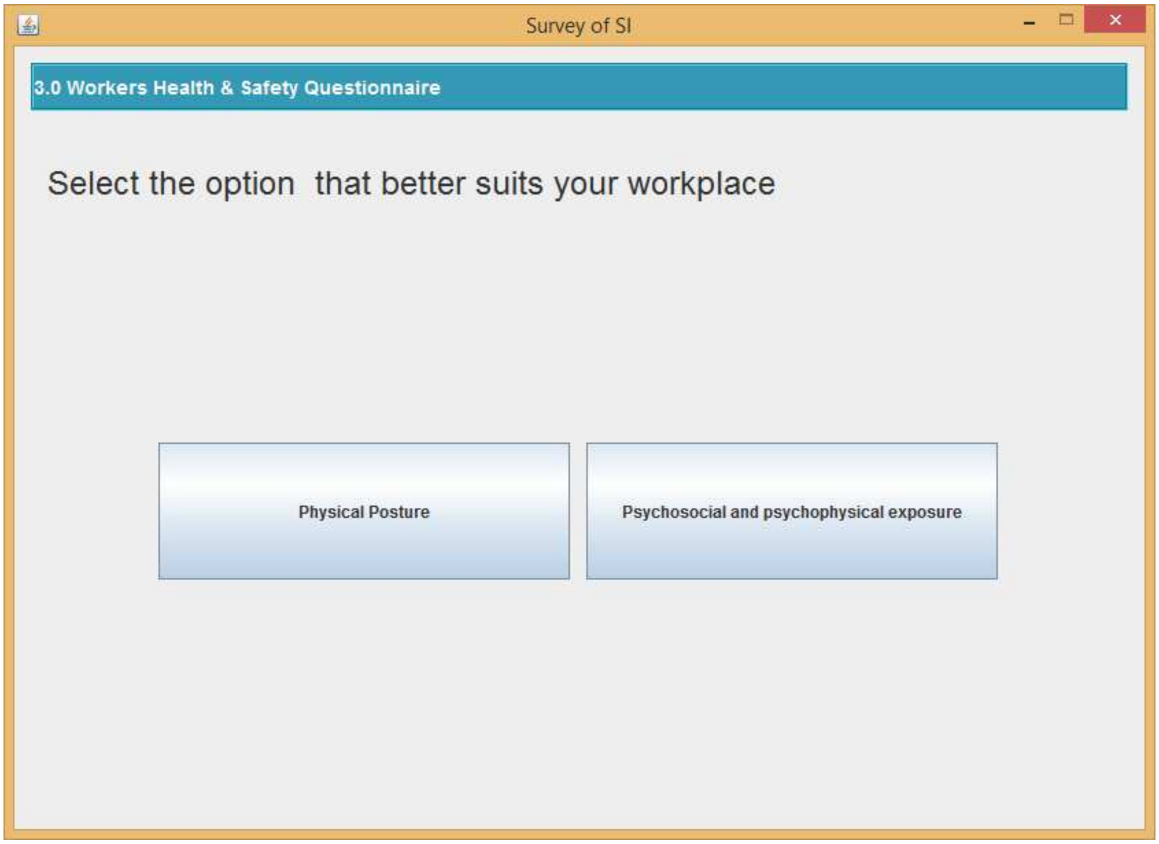


Figure 11: Gathering the Responses to Calculate U_i of Eq. (10)

4.2 Sample Results

The system determines the sustainability index and carbon footprint based on users' responses. Figure 12 shows the results section of the software. The energy section has eight subgroups. The percentage of a single subgroup compares the overall usage to the total energy consumption. Later, the energy efficiency index is given with its waste section records and waste management index.

Figure 13 represents 3 indicators relative weightage and subgroups of the workers' health and safety section. Figure 14 also provides the workers' health and safety index and overall sustainability index. At the very bottom, there is an option to check the carbon footprint reduction potential.

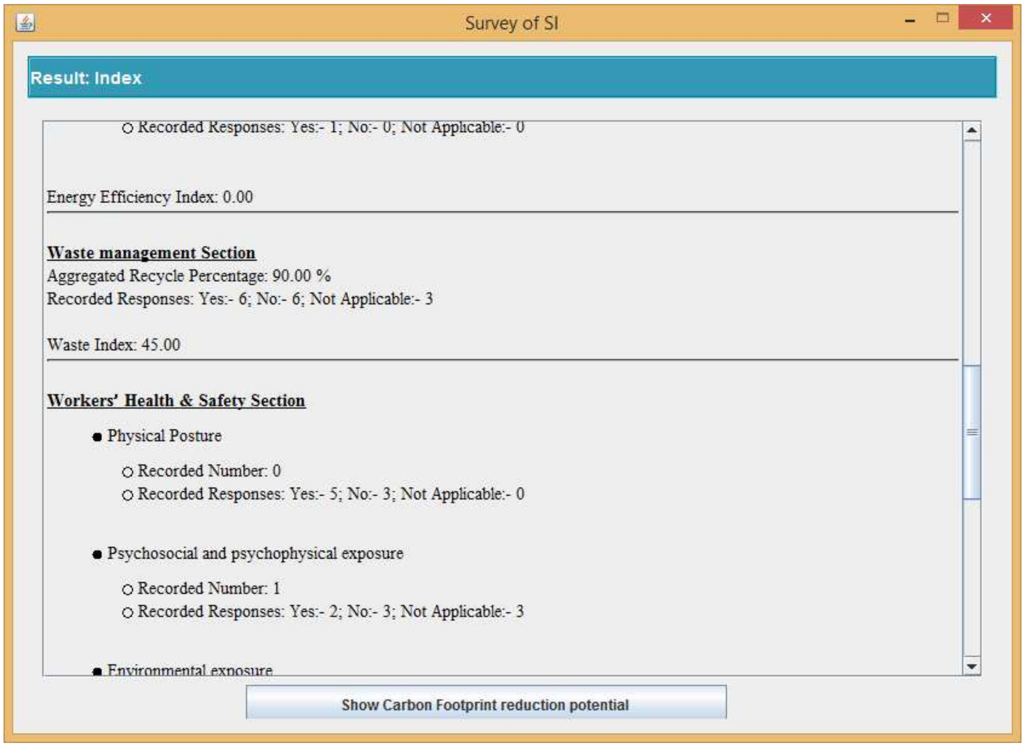


Figure 12: Sample Results for Energy and Waste Section

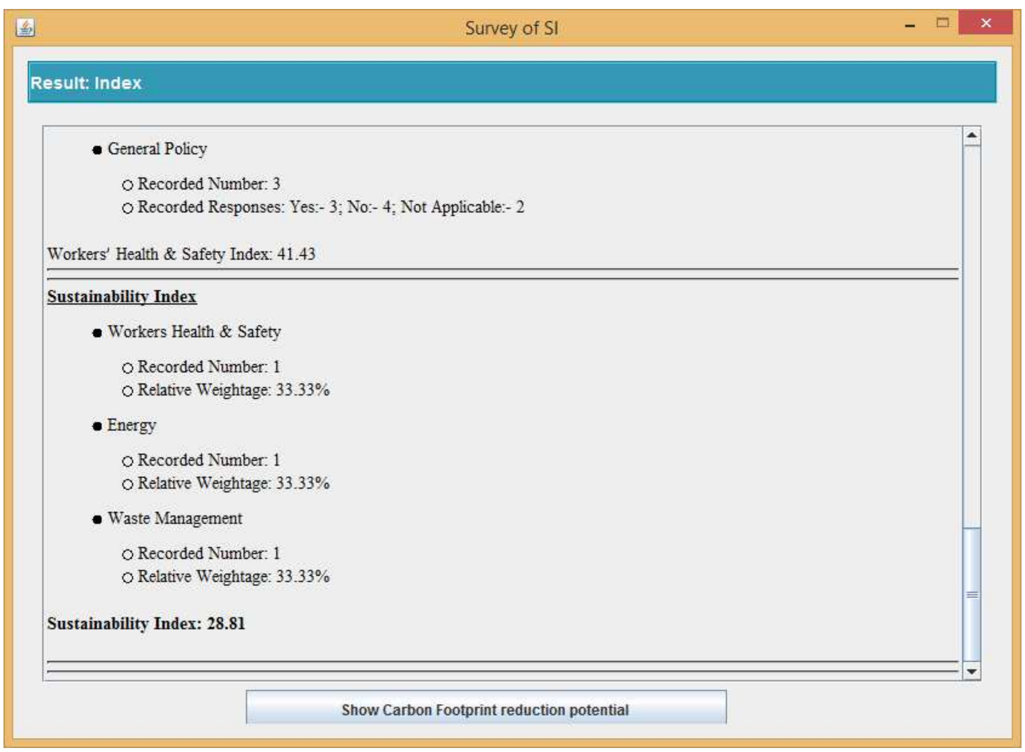


Figure 13: Sample Results for Workers' Section and Overall Sustainable Index

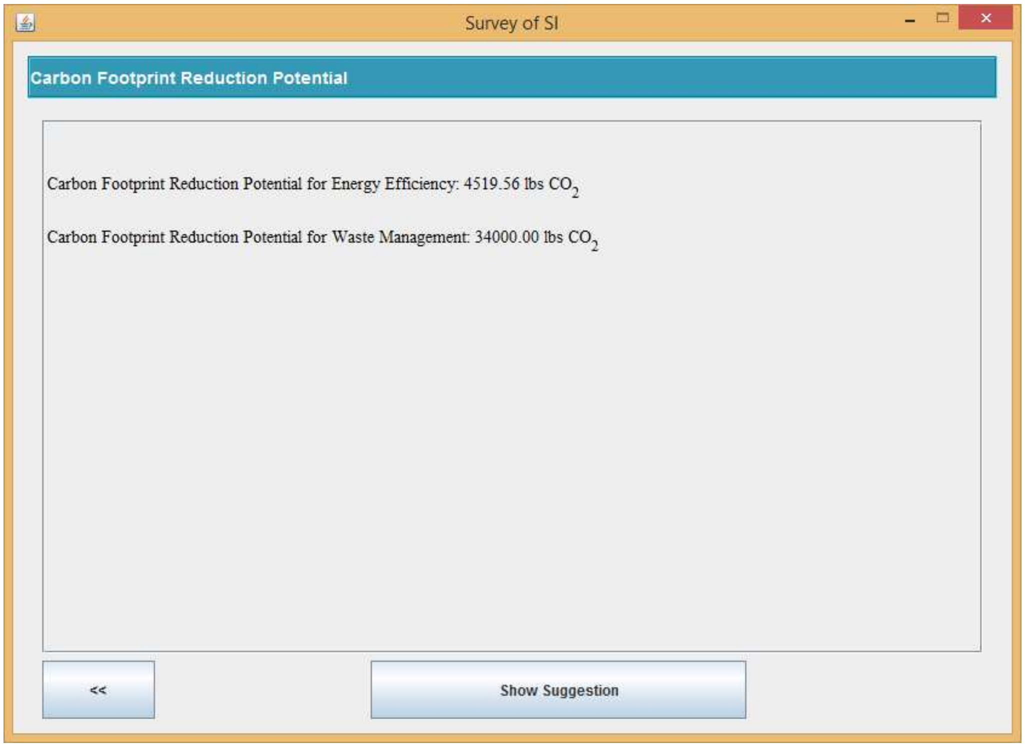


Figure 14: Carbon Footprint Reduction Potential

Figure 14 shows the reduction potential of carbon footprint. It takes into account all of the information provided by the user, and calculates the carbon footprint savings opportunity.

Figures 15a and 15b show probable suggestions that any particular company can use to improve its sustainability index. Users have the option to change their answers to see how the sustainability index changes accordingly.

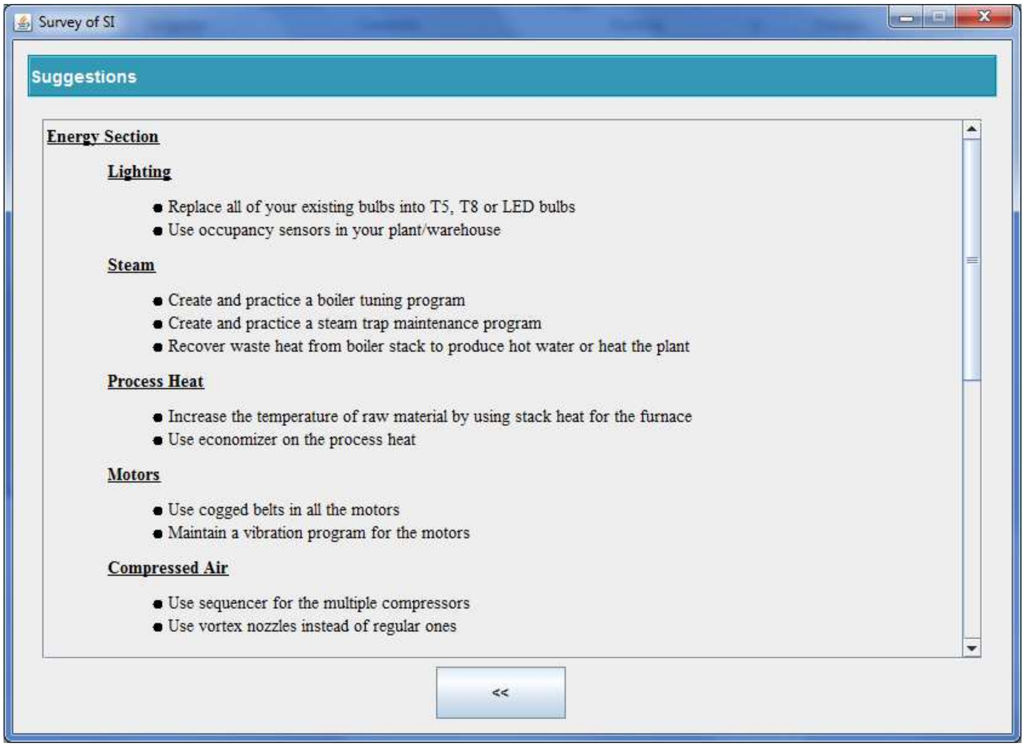


Figure 15a: Suggestions to Improve the Sustainability Index

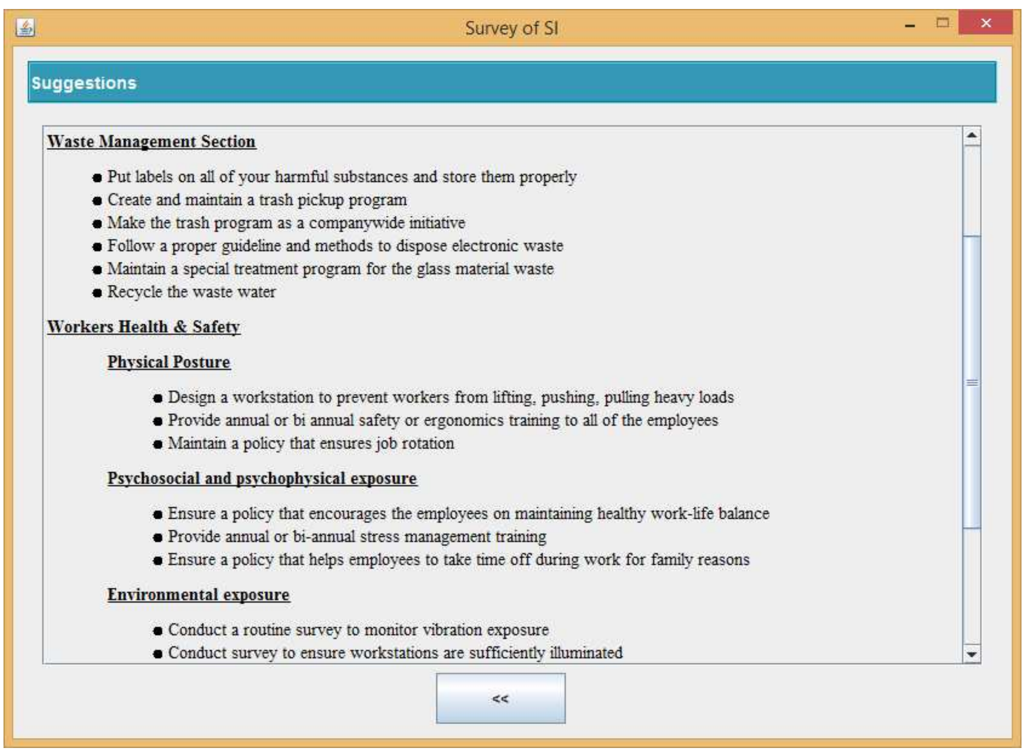


Figure 15b: More Suggestions to Improve the Sustainability Index

4.3 Conclusion

The interactive software model is capable of customize calculation. It asks the responses from the user. With the simple responses from the user, the model calculates accordingly. The model can show the indices quickly with implementation suggestions. The user can implement the suggestions and instantly check sustainability index. This way, the interactive software model can help the manufacturing industry to become sustainable.

5.0 Validation and Analysis of the Model

The model requires further analysis and validation to improve the algorithm. Different scenarios can provide a better understanding of the model. Case studies using the IAC and E3 databases can be conducted to assess and analyze the sustainability index of the manufacturing industry. Such studies are designed to optimize the relative weightage process through quantitative analysis. Users can input the usage factor, recycle percentage, and current condition of the plant to determine the sustainability index and carbon footprint reduction potential. In addition, recommendations for energy efficiency, waste management, and improvements for workers' health & safety are provided. In this section, two categories of case studies are discussed. The algorithm is used to evaluate two case studies, one case study from each category, and the results are presented.

5.1 Validation and Analysis of Case Study One

From the IAC database, one company which shows the possibility of good sustainable manufacturing practice is used to test the sustainability index. The main product of the company is automotive sensors and spark plugs. On the day of IAC assessment, plant managers participated in the survey and were given the chance to examine all the possibilities of the model. The input details from respective company personnel are described below.

At first the user form plant 1 had to select one option from each row from Table 7.

Table 7: User's Selection to Prioritize Indicators

Select the option that is more important at manufacturing plant	
Energy Usage	Waste Management
Waste Management	**Workers Health & Safety**
Workers Health & Safety	Energy Usage

* User's selections are displayed in bold letter

Based on the response, the manufacturing company prioritizes workers' health and safety, energy efficiency, and waste management. This situation matches situation 1 of Table 3.

According to Table 6, the relative weightages are 50%, 30% and 20% for energy index, waste index and worker index respectively.

For energy index calculation, total annual energy consumption profile is required for case study 1. The total annual consumption of electricity is 10,529,750 kWh/yr and other fuel (natural gas/coals/saw dust) consumption is 12,116 MMBtu/yr. Based on ePEP and recorded responses, the sustainability index is given below. Table 5 shows the total energy consumption details with respect to different subgroups. Table 8 shows the waste generation profile of the case study 1.

Table 8: Energy Consumption Details for Case Study 1

Electricity		**Fuel (Natural Gas/Coal/Sawdust)**	
Total Annual Usage (kWh/yr)	10,529,750	Total Annual Usage (MMBtu/yr)	12,116
Consumption Percentage		**Consumption Percentage**	
Sector	**Percentage**	**Sector**	**Percentage**
Lighting	10%	Lighting	0%
HVAC	0%	HVAC	30%
Steam	0%	Steam	20%
Process Heat	0%	Process Heat	50%
Pumps & Fans	25%	Pumps & Fans	0%
Motors	30%	Motors	0%
Compressed Air	15%	Compressed Air	0%
Chillers/Cooling Towers	20%	Chillers/Cooling Towers	0%
Total	100%	Total	100%

Table 9: Waste Generation Profile for Case Study 1

Waste Sector	**Total Waste Amount (tons/yr)**	**Recycling Percentage (%)**
Electronic Waste	0	-
Glass Waste	0	-
Metal Cleaning Solvent	1,200	90
Wood Waste	0	-
Waste Water	0	-
Paint Waste	0	-
Chemicals	0	-
Waste Sludge	0	-
Scrap Metal	185,000	95

At this stage, the company personnel required to answer the questions. The interactive model records the responses and formulates the equations accordingly. Table 10 displays summary of the recorded responses. Applying equation (1) to each of subgroups, performance indicator (Q_i) is calculated. For example, the first entry in the Table 10 "Lighting" has 3 positive responses and 1 negative response. Thus performance indicator of lighting is,

$$Q_i \text{ of lighting} = \frac{3}{3+1}\% = \frac{3}{4}\% = 75\%$$

Table 10: Summary of Recorded Responses from Energy Sector

Sub groups	Number of Questions	Positive Response	Negative Response	Not-Applicable Response	Performance Indicator, Q_i
Lighting	4	3	1	0	75%
HVAC	4	2	2	0	50%
Steam	7	0	1	6	0%
Process Heat	2	0	2	0	0%
Pumps & Fans	2	1	0	1	100%
Motors	4	2	2	0	50%
Compressed Air	5	2	3	0	40%
Chillers/ Cooling Towers	1	1	0	0	100%

By using equation (2), consumption of the subgroup can be calculated. For example, the first entry in Table 8 "Lighting" has 10% of total electricity consumption and 0% fuel (natural gas/coals/saw dust) consumption. Thus consumption percentage with respect to total energy becomes,

$$\frac{0.10 \times \frac{10,529,750}{293} + 0 \times 12,116}{\frac{10,529,750}{293} + 12,116}\% = 7.48\%$$

Now applying equation (3) to all of the subgroups of energy, the energy index can be found. Performance indicator and consumption percentage of each subgroup are displayed in Table 11. Thus energy index is

Energy Efficiency Index = (75% x 7.48% + 50% x 7.56% + 0% x 5.04% + 0% x 12.61% + 100% x 18.70% + 50% x 22.44% + 40% x 11.22% + 100% x 14.96%) 100%

= 58.76

In the last 5 years, the management has implemented more than 10 projects designed to improve these areas. From equation (4), the value of 'P' is found as 0.05. Using equation (4), the possible carbon footprint savings is calculated. The potential carbon footprint savings for energy efficiency are given as below.

Carbon Footprint Reduction Potential

$$=[\sum_{i=1}^{8}\{(1-Q_i)\times x_{ie}\}\times a_e\times 2.19\times P]+[\sum_{i=1}^{8}\{(1-Q_i)\times x_{ig}\}\times a_g\times 139\times P] \text{ lbs}$$

$$= (1-0.75)\times 10\%\times 10,529,750\times 2.19\times 0.05+(1-0.75)\times 0\%\times 10,529,750\times 139\times 0.05$$

= 28,825 lbs CO_2

Similarly, by applying the equation (4) to the each of subgroups, total carbon footprint reduction potential is shown in Table 11.

Table 11: Calculated Parameters for Each Subgroups of Energy

Sub groups	Performance Indicator, Q_i	Consumption Percentage	Carbon Footprint Reduction (lbs CO_2)
Lighting	75%	7.48%	28,825
HVAC	50%	7.56%	12,631
Steam	0%	5.04%	16,841
Process Heat	0%	12.61%	42,103
Pumps & Fans	100%	18.70%	0
Motors	50%	22.44%	172,951
Compressed Air	40%	11.22%	103,771
Chillers/ Cooling Towers	100%	14.96%	0
Total			**377,122**

Now, the steps of calculating waste index is showing in the following section. Applying equation (1) to the waste management section, performance indicator (Q_i) is calculated. In total, the waste management has 7 positive responses and 2 negative responses with 6 "Not Applicable" responses. Thus performance indicator of waste management is,

Q_i of waste management = $\frac{7}{7+2}\% = \frac{7}{9}\% = 78\%$

Now applying equation (5) to Table 6, aggregated recycling percentage is calculated.

Aggregated recycling percentage = $\frac{1,200 \times 90 + 185,000 \times 95}{1,200 + 185,000}\% = 94.97\%$

By using equation (6), waste management index is found.

Waste Management Index = (94.97% x 78%) x 100% = 73.86

Using equation (7), the possible carbon footprint savings is calculated. The amount is not significant because of the plant's affinity for recycling the accumulated waste. The value of Y_j is found from Table 2. The carbon footprint savings for waste management are given as below.

$$\text{Carbon Footprint Reduction Potential} = [\sum_{j=1}^{9} \{(1-R_j) \times t_j\} \times Y_j] \text{ lbs } CO_2$$

= {(1-0.90) x 1,200 x 113} + {(1-0.95) x 185,000 x 19,510} lbs CO_2
= 180,481,060 lbs CO_2

For the workers' health and safety part, the user form plant 1 had to select one option from each row again from Table 12.

Table 12: User's Selection to Prioritize Subgroups of Workers' Health and Safety

Select the option from each row that better suits your workplace	
Physical Posture	**Psychosocial and psychophysical exposure**
Environmental Exposure	General Policy
Physical Posture	**Environmental Exposure**
Physical Posture	General Policy
Environmental Exposure	Psychosocial and psychophysical exposure
General Policy	**Psychosocial and psychophysical exposure**

* User selections are displayed in bold letter

Based on the response, the manufacturing company prioritizes environmental exposure with 3 selections, psychosocial and psychophysical exposure with 2 selections, physical posture with 1 selection and general policy with no selection. Applying equation (1) to the worker section, performance indicator (Q_i) is calculated. Table 13 shows the recorded responses and performance indicators. By using equation (8) on the selection number, relative weightage can be found in Table 11. For example, relative weightage of psychosocial and psychophysical exposure with 2 selections is given as below.

Relative weightage of psychosocial and psychophysical exposure = $\frac{2}{6}$ = 0.33

Table 13: Summary of Recorded Responses from Workers' Health and Safety

Sub groups	Number of Question	Positive Response	Negative Response	Not-Applicable Response	Performance Indicator, Q_i
Physical posture	8	3	2	3	60%
General policy	8	2	6	0	25%
Psychosocial and psychophysical exposure	9	6	3	0	67%
Environmental exposure	8	4	1	3	80%

Table 14: Different Parameters for Workers' Health and Safety

Sub groups	Selection Number	Relative Weightage, U_i	Performance Indicator, Q_i
Physical posture	1	0.17	60%
General policy	0	0	25%
Psychosocial and psychophysical exposure	2	0.33	67%
Environmental exposure	3	0.50	80%

Now applying equation (9) to all of the subgroups of table 6, the worker' health and safety index can be found. Performance indicator and relative weightage of each subgroup are displayed in Table 14. Thus workers health and safety index is given below.

Workers' Health and Safety Index = (0.17 x 60% + 0 x 25% + 0.33 x 67% + 0.50 x 80%)

= 72.61

After calculating all the indicators indices, it is quite simple to calculate overall sustainability index. By using equation (10), overall sustainability is calculated. Relative weightage of each indicators is determined from Table 3.

$$\text{Overall Sustainability Index} = \frac{0.3 \times 58.76 + 0.2 \times 73.86 + 0.5 \times 72.61}{(0.5 + 0.3 + 0.2)}$$

$$= 68.71$$

Table 11 displays the energy index, as well as breaking down the major energy consumption areas into Motors (22.44%), Pumps & Fans (18.70%) and Chillers/Cooling Towers (14.96%) with their respective recorded responses. Motors subgroup has 2 “Yes” and 2 “No” responses, Chillers/Cooling Towers subgroup has 1 “Yes” response and Pumps % Fans subgroup has 1 “Yes” response with 1 “Not Applicable” response. Table 12 shows waste generation profile which helps to calculate aggregated recycling percentage (94.97%) and recorded responses with waste management index. In addition to that, recorded responses, selection numbers and relative weightage for overall sustainability index are mentioned in Table 13. This results in an energy efficiency index score of 58.76. For waste management, the index score is 73.86, due to the fact that the company is doing quite well with 7 “Yes” and 2 “No” responses.

Moreover, Table 13 shows that psychosocial and psychophysical exposure received 2 selections, environmental exposure received 3 selections and physical posture subgroup received 1 selection. Since the plant claims to value workers’ health & safety, the workers’ health and safety index score is 72.61, it shows good overall sustainability index of 68.71.

Figure 16 displays a part of implementation suggestions based on the user response. If the plant can execute these implementations, sustainability index will be higher.

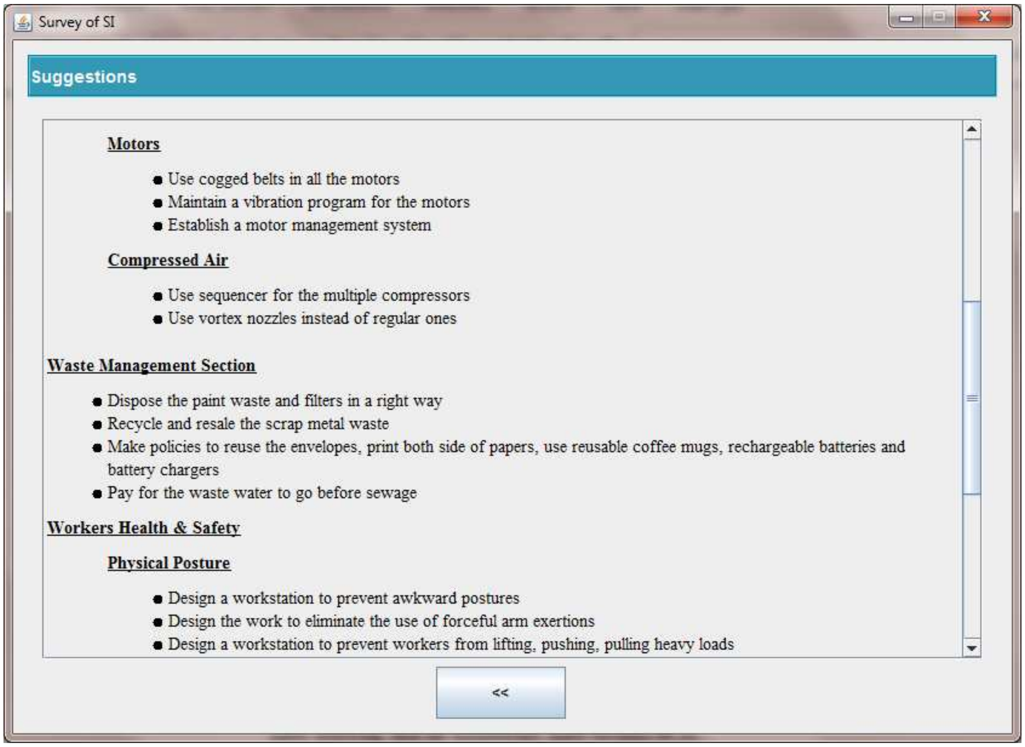


Figure 16: Part of Implementation Suggestions for Case Study 1

It is very important to focus on the right sector. For example, by changing the focus on energy, the sustainability index can instantly be altered. If the priorities are arranged in a way where waste management is foremost with energy efficiency and workers' health and safety following, then the sustainability index becomes 69.14.

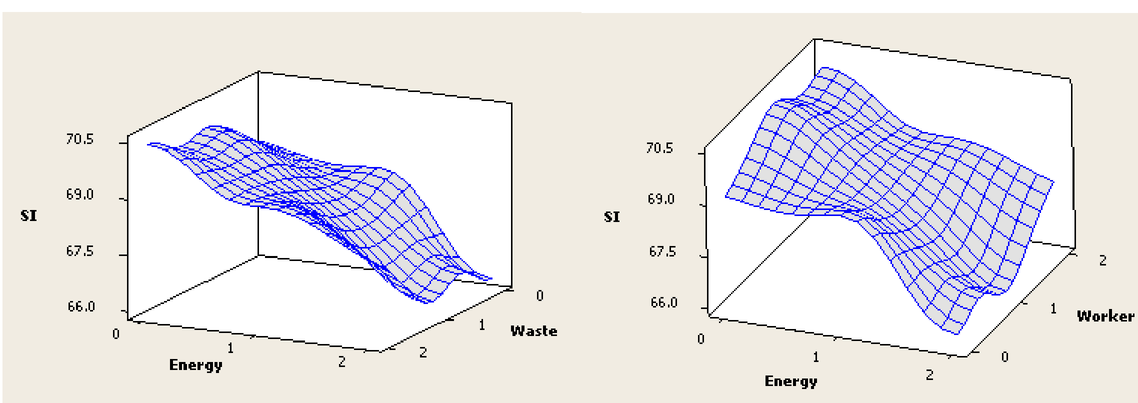


Figure 17: Surface Plot of Sustainability Index vs Worker, Energy and Sustainability Index vs Waste, Energy

Figure 17 demonstrates a relative comparison of sustainability index between waste and worker with respect to energy. Sustainability index shows inclination towards the indicator with higher index. For example, whenever energy gets low priority, sustainability index reflects higher number. If priority of energy remains same, prioritizing waste can reflect higher sustainability index.

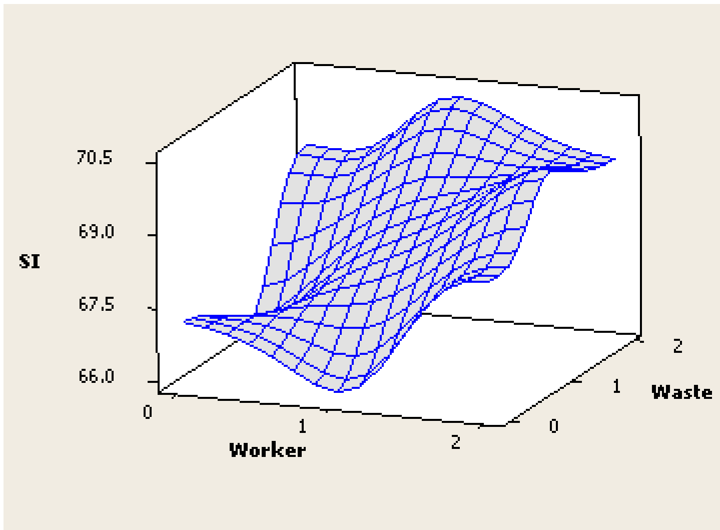


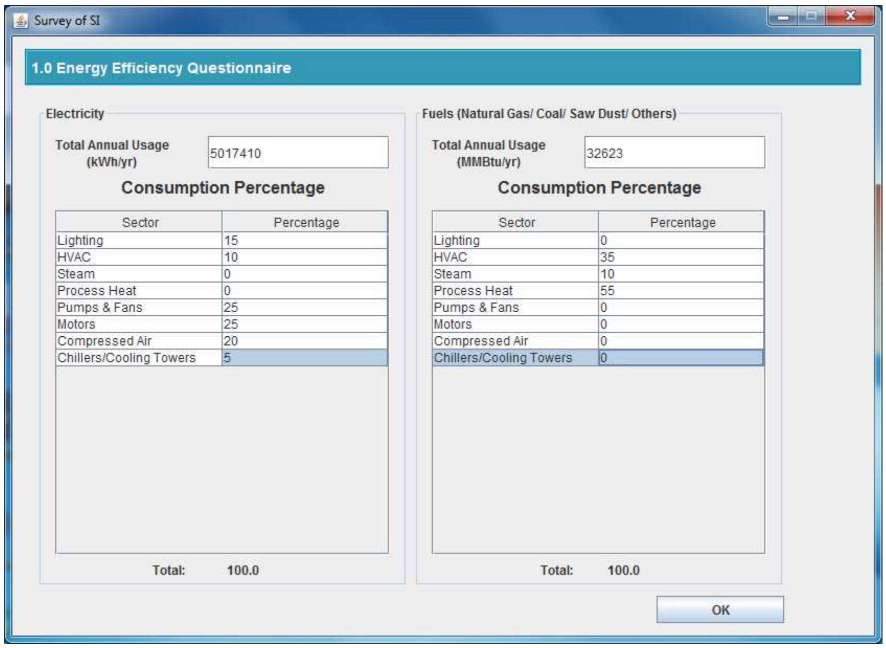
Figure 18: Surface Plot of Sustainability Index vs Worker, Waste

By observing Figure 18, it is evident that the sustainability index can be improved by focusing on the highest individual factor's index. For example, the sustainability index can be improved by focusing more on waste and worker. This observation also helps to prioritize the suggestions.

5.2 Validation and Analysis of Case Study Two

From the IAC database, another company that shows the possibility of average sustainable manufacturing practice is used to test the sustainability index. The company's main product is rolled aluminum foil. On the day of IAC assessment, the maintenance manager participated in the survey and was given the chance to explore all the possibilities of the model. The input detail of the respective company personnel are given below.

The manufacturing company prioritizes waste management, then energy efficiency and finally workers' health and safety. This case study is described by the software model. In the last 5 years, the management has implemented less than 5 projects in these areas. The total annual consumption of electricity is 5,017,410 kWh/yr and fuel (natural gas/coals/saw dust) consumption is 32,623 MMBtu/yr. Based on ePEP and recorded responses, the sustainability index is given below.


Survey of SI

1.0 Energy Efficiency Questionnaire

Electricity

Total Annual Usage (kWh/yr): 5017410

Consumption Percentage

Sector	Percentage
Lighting	15
HVAC	10
Steam	0
Process Heat	0
Pumps & Fans	25
Motors	25
Compressed Air	20
Chillers/Cooling Towers	5

Total: 100.0

Fuels (Natural Gas/ Coal/ Saw Dust/ Others)

Total Annual Usage (MMBtu/yr): 32623

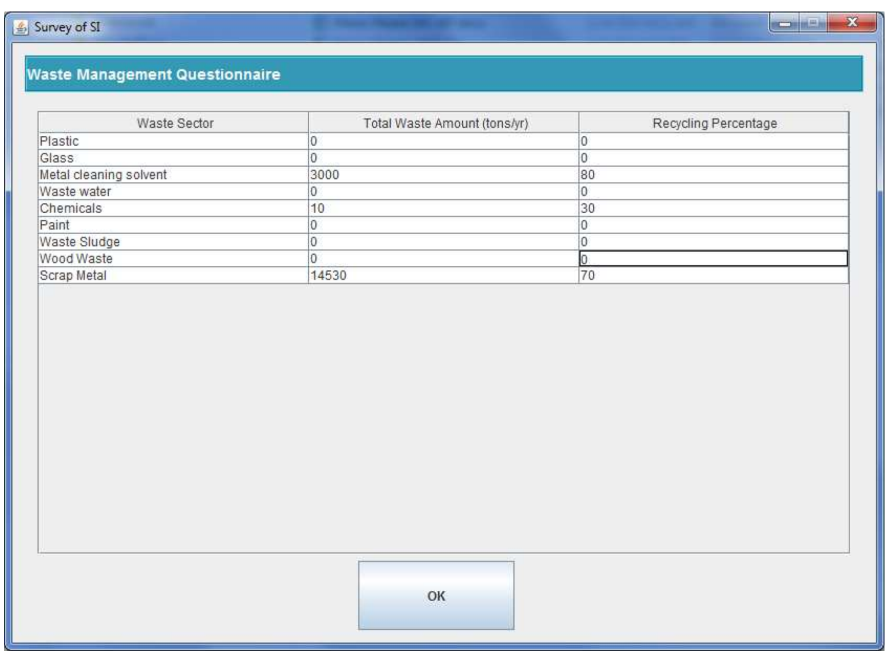
Consumption Percentage

Sector	Percentage
Lighting	0
HVAC	35
Steam	10
Process Heat	55
Pumps & Fans	0
Motors	0
Compressed Air	0
Chillers/Cooling Towers	0

Total: 100.0

OK

Figure 19a: Energy Consumption Profile for Case Study 2


Survey of SI

Waste Management Questionnaire

Waste Sector	Total Waste Amount (tons/yr)	Recycling Percentage
Plastic	0	0
Glass	0	0
Metal cleaning solvent	3000	80
Waste water	0	0
Chemicals	10	30
Paint	0	0
Waste Sludge	0	0
Wood Waste	0	0
Scrap Metal	14530	70

OK

Figure 19b: Waste Generation Profile for Case Study 2

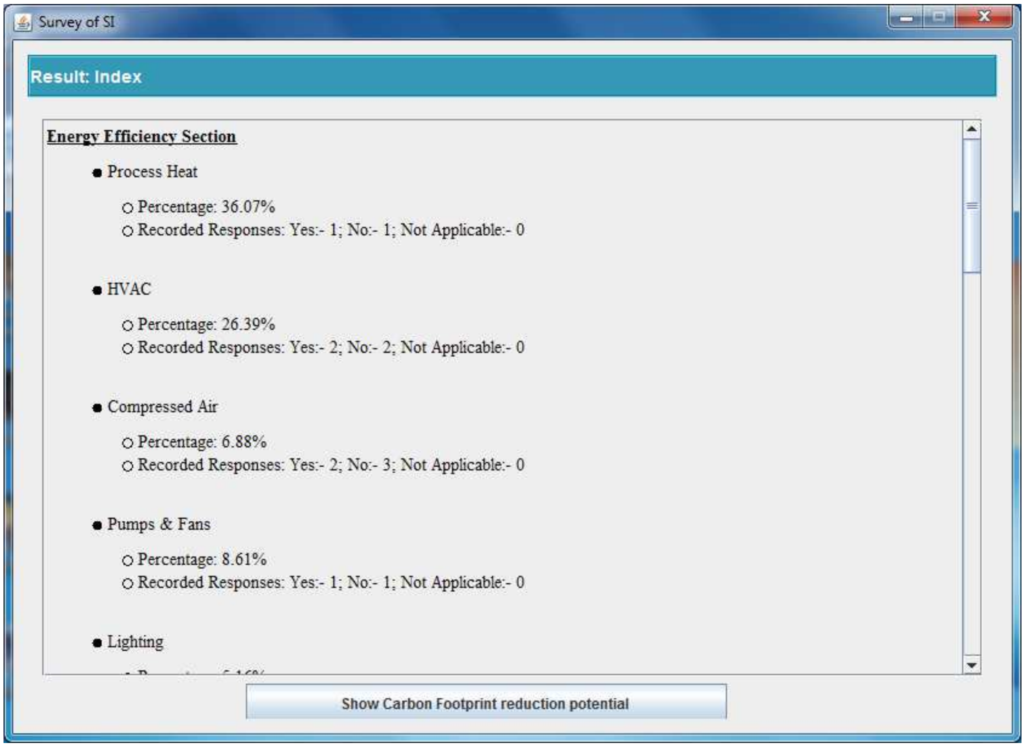


Figure 20a: Energy Consumption Percentage for Case Study 2

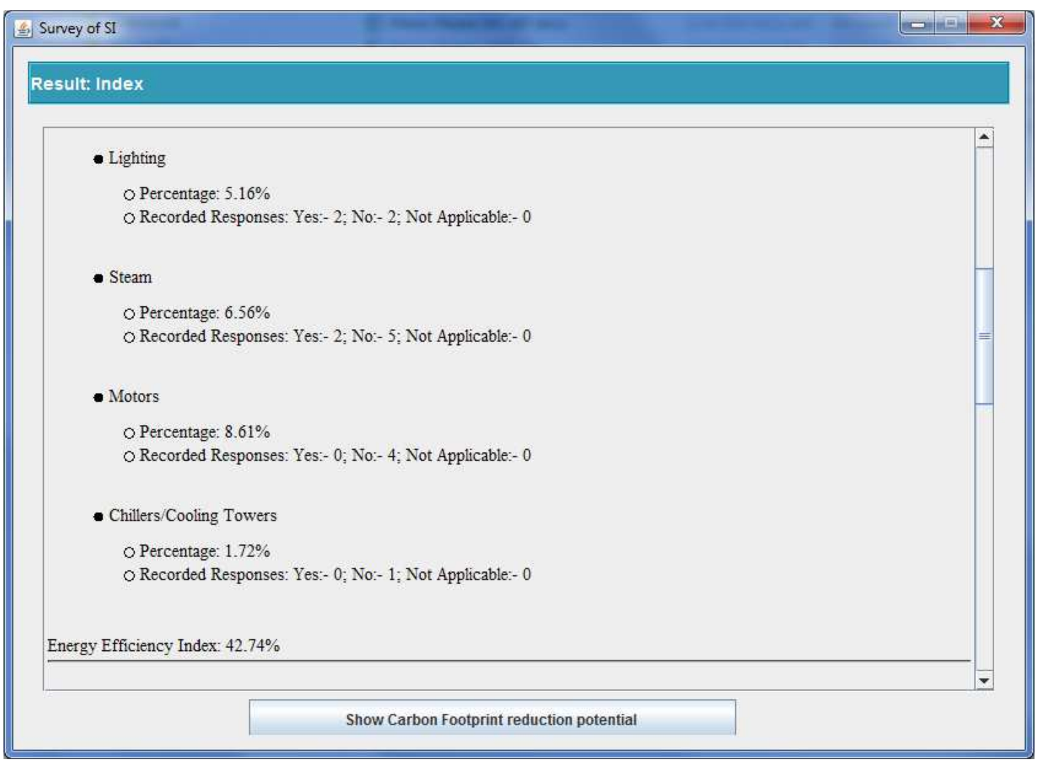


Figure 20b: Overall Consumption Percentage of Subgroups for Case Study 2

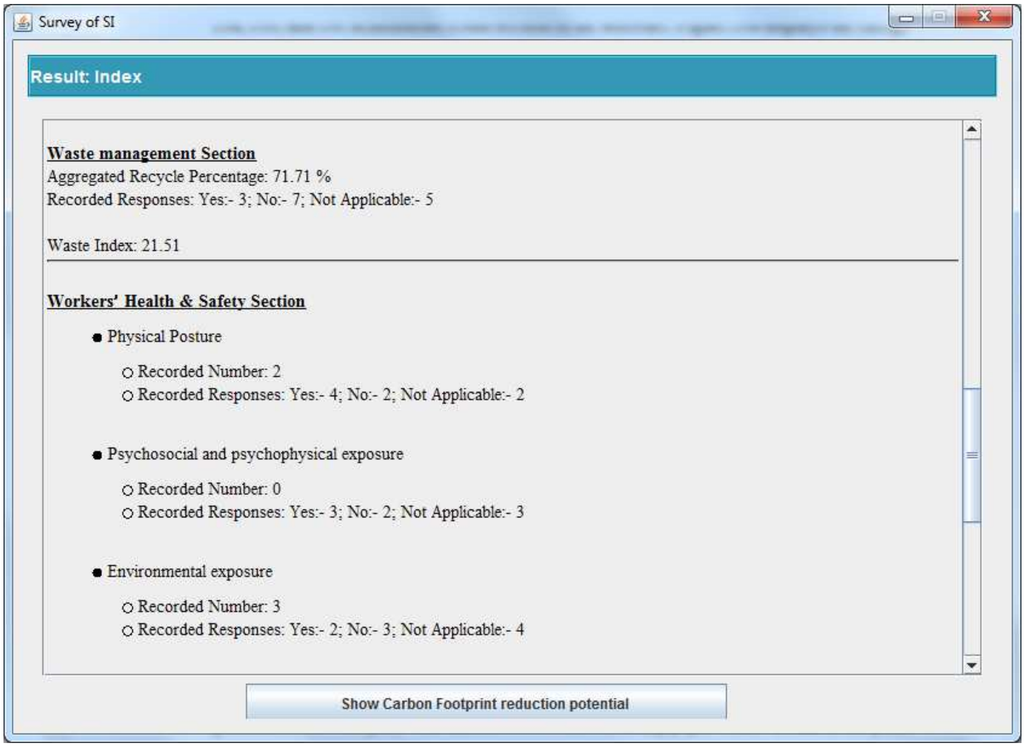


Figure 20c: Waste Management Index for Case Study 2

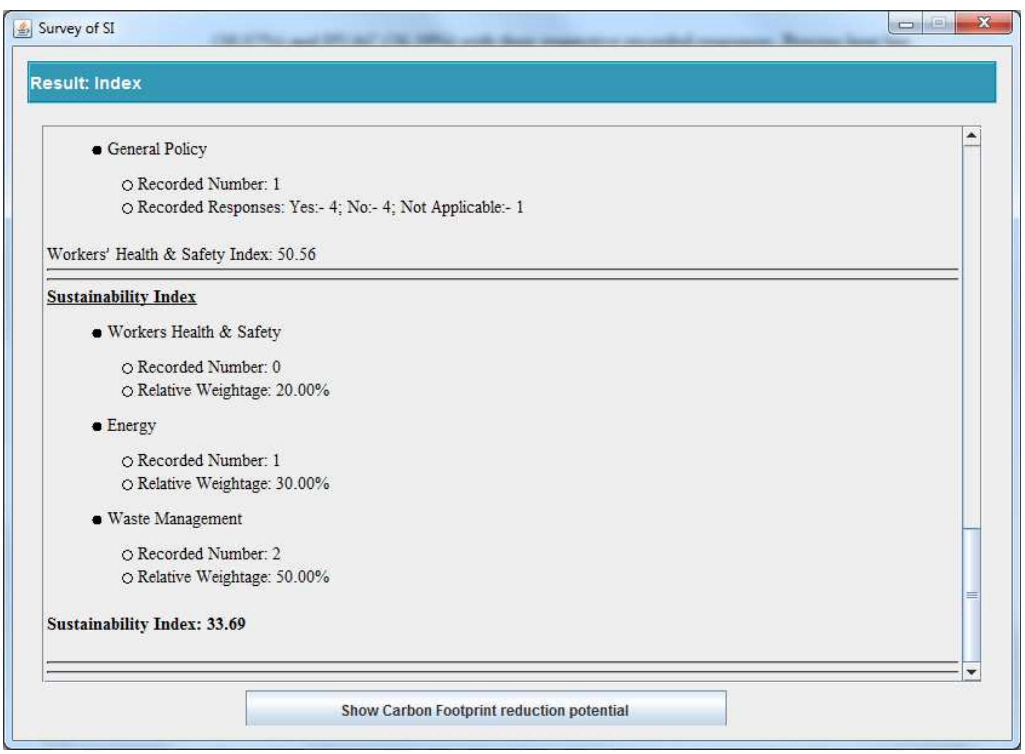


Figure 20d: Overall Sustainability Index for Case Study 2

Figures 19 and 20 illustrate the sustainability index for Skana Aluminum Company. Figure 19a and 19b show energy consumption percentage and waste generation profile for respective subgroups. By using ePEP software, the consumption profile is prepared. Figure 20a, 20b, 20c and 20d demonstrate result section of the software. Figure 20a displays the energy index, as well as breaking down the major energy consumption areas into Process heat (36.07%) and HVAC (26.39%) with their respective recorded responses. Process heat has 1 "Yes" and 1 "No" response, HVAC has 2 "Yes" responses and 2 "No" responses with no "Not Applicable" responses. Figure 20b is showing energy efficiency index. Figure 20c shows aggregated recycling percentage (71.71%) and recorded responses with waste management index. In addition to that, recorded responses, selection numbers and relative weightage for overall sustainability index are mentioned in Figure 20d. This results in an energy efficiency index score of 42.74. For waste management, the index score is 21.51, due to the fact that the company is performing poorly with 3 "Yes" and 7 "No" responses. For workers' health & safety section, index is 50.56.

Moreover, Figure 20c and 20d show that physical posture received 2 selections, environmental exposure received 3 selections and general policy subgroup received 1 selection. Though the plant claims to value waste management, the waste management index score is only 21.51, lowering the overall sustainability index to 33.69.

For the waste management part, the index score is 21.51 where the manufacturing industry is performing poorly with 3 "Yes" and 7 "No" responses. Despite its focus on waste management, the plant lacks in the area of general waste. For example, the plant is not very concerned with reusing paper, envelopes or rechargeable batteries. In addition, the plant has responded negatively towards trash pickup programs, electronic waste disposal guidelines, and companywide initiatives towards handling paper waste. Besides, the plant has relatively low aggregated recycling percentage (71.69%).

Figure 21 represents the carbon footprint savings amount in terms of lbs CO_2, which is calculated from equation (4) and (7). The amount is not significant because of the plant's affinity for recycling the accumulated waste.

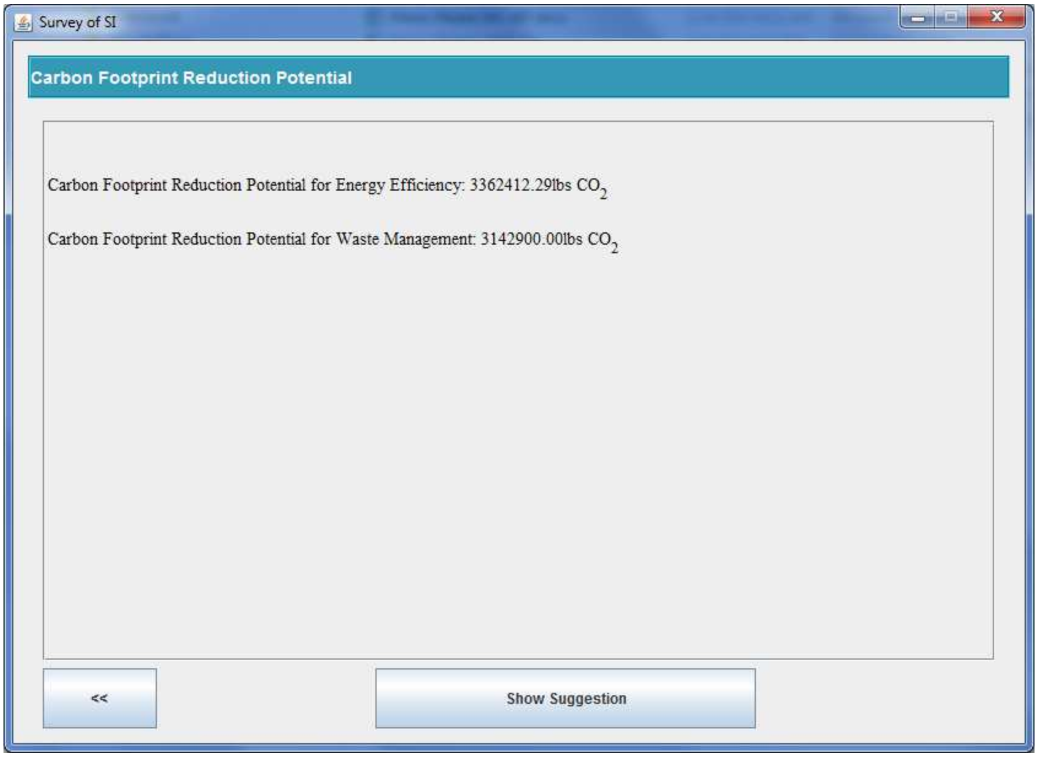


Figure 21: Carbon Footprint Reduction Potential for Case Study 2

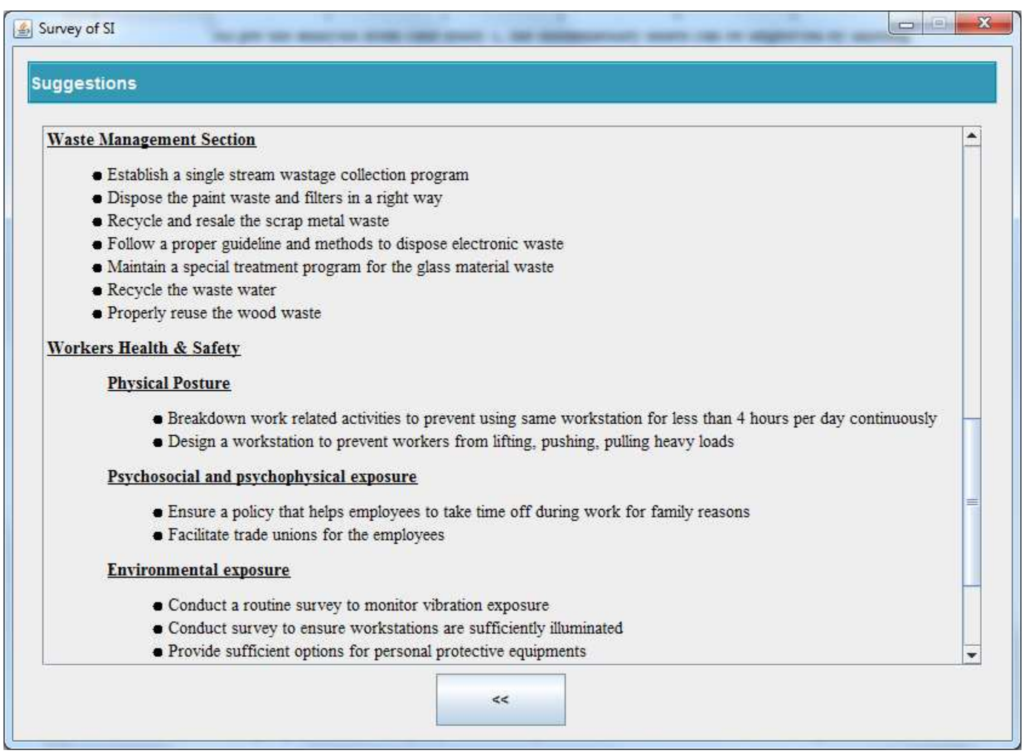


Figure 22: Part of Implementation Suggestions for Case Study 2

The sustainability index is low because of their low score on waste management, in spite of the company's claim that they focus on this area. Surprisingly, the plant performed relatively better on workers' health and safety, with an index score of 50.56. Since the plant deals with hot rolling aluminum foil, the workers take mandatory safety precautions. It is difficult to move the hot rolled product from one place to another, which is why the plant is equipped with assisting equipment such as pallet trucks, movable cranes, and accessible safety instructions. . If the plant shifts its focus to improving workers' health and safety, then energy efficiency and finally waste management, then the sustainability index score becomes 42.41.

As per the analysis from case study 1, the sustainability index can be improved by shifting the focus on the workers' health and safety. The user just has to select workers' health and safety in the questionnaire as the primary focus area; however, this does not improve the actual environment. Figure 26 displays the part of implantation suggestions from the model that can be implemented for a better sustainability index score.

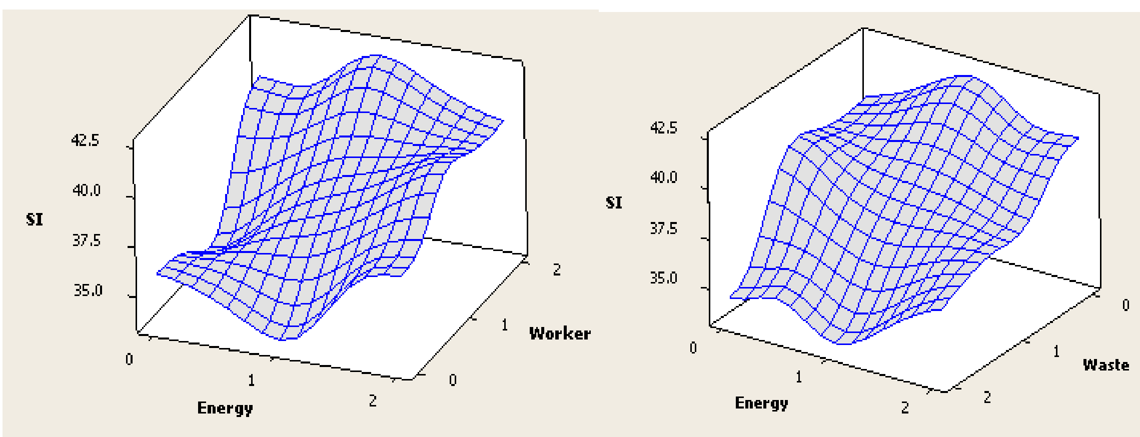


Figure 23: Surface Plot of Sustainability Index vs Worker, Energy and Sustainability Index vs Waste, Energy

Figure 23 and 24 reinstate the analysis of case study 1, which is focusing on the high indicator's index can deliver better sustainability index. These figures also represent how the sustainability index changes when the focus changes from energy efficiency, to waste management or workers' health and safety. Therefore, focusing on workers appears to be the right path for the company. Since the plant claims to focus on waste management, this indicates that major overhaul is still needed. This observation helps to prioritize the implementation suggestions.

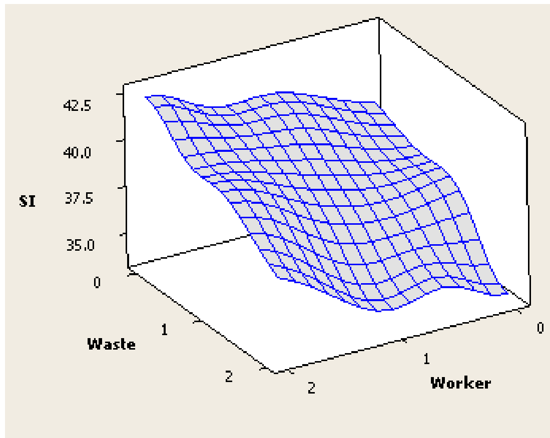


Figure 24: Surface Plot of Sustainability Index vs Worker, Waste

By understanding how focusing on different areas can affect the sustainability index, a strategic plan can be developed. With the aforementioned significance of the sustainability index, real change can be achieved by attempting to improve the company's performance. The company, as well as society, can benefit by implementing the suggestions

At this point of the discussion, it is important to analyze which implementations require immediate attention. Assuming that, Skana Aluminum decides to implement 5 projects from each of the sectors.

<u>Situation 1:</u>

Assuming the plant implements 5 projects from energy sector. The 5 implementations are given as below.

1. Installing economizer on the process heat
2. Using VFD on large pumps and fans which have variable load
3. Using occupancy sensors in warehouse
4. Establishing motor management system

5. Creating vibration program.

After running the model again, the sustainability index stands as 42.07 and energy efficiency index is 70.67 from 42.74. So the energy index has increased 65% with 5 implementations.

<u>Situation 2:</u>

Assuming the plant implements 5 projects from waste management. The 5 implementations are given as below.

1. Placing labels on all of the harmful substances and storing them properly
2. Establishing a trash pickup program
3. Making the trash program as a companywide initiative
4. Establishing a single stream waste collection program
5. Following a proper guideline and methods to dispose electronic waste

After running the model again, the sustainability index stands as 51.61 and waste management index is 57.35 from 21.51. So the waste management index has increased 167% with only 5 implementations. Since the number of factors are very limited and the plant has a decent aggregated recycling percentage, implementations on this segment has better impact than other two sections.

<u>Situation 3:</u>

Assuming the plant implements 5 projects from workers' health & safety. The 5 implementations are given as below.

1. Creating a good work-life balance
2. Re designing the work so that moderate force is enough to perform the task.
3. Stopping repetitive motions such as lifting, pushing, and bending
4. Using proper protection for noisy environment
5. Facilitating strong trade unions

After running the model again, the sustainability index stands as 38.74 and workers' health and safety index is 75.83 from 50.56. So the workers' health & safety index has increased 50% with only 5 implementations.

From this analysis, it is observed that focusing on the prioritized segment can have a better impact on the sustainability index. Overall sustainability index gets affected by the plant's focus. Implementations on waste management will provide better sustainability index. As an example of the impact of these suggestions, industry personnel can focus on the waste-related suggestions so that the immediate impact will be greatest.

Carbon footprint reduction potential is inversely related to sustainability index. If sustainability index increases, the carbon footprint reduction savings amount decreases. When a plant is achieving good sustainability index, few implementation suggestions are available. Thus, opportunities for reducing carbon footprint will be reduced and hence the carbon footprint reduction potential will be lower. Similarly, when sustainability index decreases, the carbon footprint savings potential will be higher. For example, case study 1 shows the overall sustainability index as 58.76 with 377,122 lbs CO_2 carbon footprint savings potential for energy efficiency. After implementing 5 suggestions from energy section, the overall sustainability index becomes 74.09 with 100,400 lbs CO_2 carbon footprint savings potential for energy efficiency. Carbon footprint savings potential can provide a greater rebate from the government. These numbers have the potential to provide additional benefits on top of creating a better image and better society.

6.0 Conclusion

In this research, the manufacturing industries' situations have been studied and factors influencing sustainable manufacturing have been discovered. In order to achieve sustainable manufacturing in a competent way, it is important to have a meaningful sustainability index through which manufacturing industries can compare among themselves and measure internal improvement. For this reason, a model has been designed by selecting significant factors and integrating them in various ways.

The developed model has been justified using various techniques and reflects realistic approaches in the manufacturing plants. Pairwise comparison, weighted average, normalization techniques, and relative adaptive weighting methods form the backbone of the model. The adaptability, globalization and portability features have been given prominence while designing the model. The model was transferred into a software by using Java® code.

The software takes inputs from users and adapts the weightings according to the input. Based on the inputs, it provides a sustainability index score for the three factors individually, as well as the overall score. The software also shows the carbon footprint score and suggestions that may help the particular company improve sustainability. The analysis shows that giving the lowest performing factor the highest priority leads to the fastest improvement in sustainability. The carbon footprint score adds another measurement to help understand the impact the company is having on the earth.

Obtained results and graphs are meaningful and reflect the realistic situation. Two case studies were run through the model. The individual factor indices and overall sustainability index show the sensitivity towards changes and ultimately provide guidance towards improvement. Though the model works well, it can still be improved. This research has performed the first and most critical step, but many interesting research questions remain unanswered. The author's recommendations for further improvement are as follows:

- Weight the questions and factors inside each subgroup based on the overall impact. For example, using dimmer control in lighting saves less than installing T8 bulbs in the facility. The current model does not differentiate the weight of these factors. In future, the questions can be weighted and impact differently in the energy efficiency index.
- Categorize implementation suggestions with respect to cost and impact factors. The author envisions this as the database taking input from the user and calculating the potential savings as well as the payback. Because situations can vary among industries, care will need to be taken to ensure the general model is representative.
- Add more questions as well as factors to make the model more robust. However, it is necessary to limit the number of questions so that the survey does not take too much time to complete.
- Incorporate the ability to consider large-scale manufacturing industries. This requires adding the capability to deal with variations of fuel, workstations, energy equipment, and types of waste.
- After collecting and maintaining a database, a standard approach can be prepared. This standard approach will help to identify the quantitative range of the sustainability index.

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Appendix

Data Collection Form

Dear Participant, My name is Hasan Latif and I am a graduate student at West Virginia University. I would like to invite you to participate in my research project as I am assessing the challenges associated with measuring performance for sustainable manufacturing for small to medium scale manufacturing industries. This research is being performed under the supervision of Dr. Bhaskaran Gopalakrishnan, a professor in the Benjamin M. Statler College of Engineering and Mineral Resources and director of the Industrial Assessment Center at WVU, in fulfillment for the degree of Master of Science in Industrial Engineering. Your participation in this project is greatly appreciated. It will take approximately 30 minutes to fill out the following questionnaire. Your involvement and any information provided in this project will be kept confidential with all data being reported in aggregate. At the end of the questionnaire, you will also have the option to request a copy of the results from the study. I hope you participate in my research project and wish to thank you for your time. For any questions or information about the questionnaire, please contact: Hasan Latif, West Virginia University, Department of Industrial and Management Systems Engineering PO Box 6070, Morgantown, WV 26506-6107 Phone: (304) 777-7871 Fax: (304) 293-4970 E-mail: hhlatif@mix.wvu.edu

Select the option between each row that is more important in your manufacturing plant	
Energy Usage	Waste Management
Waste Management	Workers Health & Safety
Workers Health & Safety	Energy Usage

1.0 Energy Efficiency Questionnaire

How many projects you have implemented to improve your energy efficiency in last 5 years?

Less than 5 projects	5-10 projects	More than 10 projects

Electricity		Fuel (Natural Gas/Coal/Saw Dust)	
Total Annual Usage (kWh/yr)		Total Annual Usage (MMBtu/yr)	
Consumption Percentage[7]		**Consumption Percentage**	
Sector	**Percentage**	**Sector**	**Percentage**
Lighting		Lighting	
HVAC		HVAC	
Steam		Steam	
Process Heat		Process Heat	
Pumps & Fans		Pumps & Fans	
Motors		Motors	
Compressed Air		Compressed Air	
Chillers/Cooling Towers		Chillers/Cooling Towers	
Total		Total	

1.1 Lighting

- Does your plant have more than 80% of T5 or T8 fluorescent or LED light?

  Yes / No/ Not Applicable
- Do you use occupancy sensors in your plant/warehouse?

  Yes / No/ Not Applicable
- Do you use skylights in your plant?

  Yes / No/ Not Applicable
- Do you use dimmer controls in your plant?

  Yes / No/ Not Applicable

1.2 HVAC

- Do you use economizers on the HVAC units?

  Yes / No/ Not Applicable
- Do you have setback temperature controls during nights and weekends?

  Yes / No/ Not Applicable
- Do you maintain the least possible temperature difference between inside and outside of the plant and office areas?

  Yes / No/ Not Applicable

[7] Additional help on defining usage percentage can be generated from ePEP software which is available at https://ecenter.ee.doe.gov/EM/tools/Pages/ePEP.aspx

- Have you checked the dock door seals in last 5 years?
  Yes / No/ Not Applicable

<u>1.3 Steam</u>

- Do you have an air to fuel boiler tuning program?
  Yes / No/ Not Applicable
- Does air to fuel ratio of your burner stay within 3.0% to 5.0%?
  Yes/ No/ Not Applicable
- Is the burner used in process heating equipment or boilers in your factory less than 20 years old?
  Yes / No/ Not Applicable
- Do you have a steam trap maintenance system?
  Yes / No/ Not Applicable
- Are you recovering waste heat from boiler stack to produce hot water or heat the plant?
  Yes / No/ Not Applicable
- Do you use adequate insulation for the boiler surface, pipeline and steam line?
  Yes / No/ Not Applicable
- Do you use economizers on the boilers?
  Yes / No/ Not Applicable

<u>1.4 Process Heat</u>

- Do you use pre-heat combustion air on the process heating equipment?
  Yes / No/ Not Applicable
- Do you increase the temperature of feed charge materials by using stack heat available in the furnace?
  Yes / No/ Not Applicable

<u>1.5 Pumps & Fans</u>

- If you have a variable working load in pumps and fans, do you use Variable Frequency Drives (VFD) on pumps and fans and other process motors as applicable?
  Yes/ No/ Not Applicable

- Do you have vibration checking program for electrical motors associated with pumps and fans?
  Yes / No/ Not Applicable

1.6 Motors

- Do you use a significant amount of cogged belts?
  Yes / No/ Not Applicable
- Do you have vibration checking program for motors?
  Yes / No/ Not Applicable
- Do you have a motor management system in term of rewinding and replacing?
  Yes / No/ Not Applicable
- Do you have capacitor banks at the motors to increase power factor?
  Yes / No/ Not Applicable

1.7 Compressed Air

- Do you have air leak checking program?
  Yes / No/ Not Applicable
- Do you use vortex nozzles for cleaning and other types of air related applications?
  Yes / No/ Not Applicable
- Do you use sequencer for controlling multiple compressors?
  Yes / No/ Not Applicable
- Do you recover the heat from the compressor exhaust?
  Yes / No/ Not Applicable
- Are the compressors discharging air at the lowest possible set pressure?
  Yes / No/ Not Applicable

1.8 Chillers/Cooling Towers

- Can you set a higher set point for cooling tower/chiller, if it does not impact production?
  Yes / No/ Not Applicable

2.0 Waste Management Questionnaire

Waste Sector	Total Waste Amount (tons/yr)	Recycling Percentage
Electronic Waste		
Glass Waste		
Metal Cleaning Solvent		
Wood Waste		
Waste Water		
Paint Waste		
Waste Sludge		
Total		

- Do you have a trash pickup program?

  Yes/No/ Not Applicable
- Is it a company-wide initiative?

  Yes/No/ Not Applicable
- Do you have single stream wastage collection program?

  Yes/No/ Not Applicable
- If you have glass materials in waste, do you separate it?

  Yes/No/ Not Applicable
- If you have metal cleaning solvents in waste, do you have proper disposable method for them?

  Yes/No/ Not Applicable
- If you have waste water, do you recycle it?

  Yes/No/ Not Applicable
- Do you pay for the waste water sewage?

  Yes/No/ Not Applicable
- Do you use chemicals to prevent scale formation in cooling towers?

  Yes/No/ Not Applicable
- If you have any scrap metal waste, do you recycle or sell it?

  Yes/No/ Not Applicable
- If you generate paint waste, do you dispose the filter in an environmentally friendly manner?

  Yes/No/ Not Applicable

- If you generate waste sludge, do you recycle it?
  Yes/No/ Not Applicable
- If you generate wood waste, do you send it to a power plant or other end users?
  Yes/No/ Not Applicable
- Is all of your harmful substances labelled and stored properly?
  Yes/No/ Not Applicable
- Do you have proper guideline and methods for electronic waste disposal?
  Yes/No/ Not Applicable
- Does your workplace perform any of these: reuse envelopes, print both side of the papers, reusable coffee mugs, use rechargeable batteries and battery chargers?
  Yes/No/ Not Applicable

3.0 Workers Health & Safety Questionnaire[8]

Select the option from each row that better suits your workplace	
Physical Posture	Psychosocial and psychophysical exposure
Environmental Exposure	General Policy
Physical Posture	Environmental Exposure
Physical Posture	General Policy
Environmental Exposure	Psychosocial and psychophysical exposure
General Policy	Psychosocial and psychophysical exposure

3.1 Physical exposure

- Do the employees hardly ever complain about work-related pain or discomfort (neck, back, upper extremity, etc.) due to physical exertion?
  Yes/No/ Not Applicable
- Are the workstations/work-activities designed to prevent use of sustained awkward postures?3
  Yes/No/ Not Applicable
- Are the workstations/work-activities designed to prevent use of forceful arm exertions?
  Yes/No/ Not Applicable

[8] http://www.cdc.gov/niosh/topics/stress/pdfs/qwl2010.pdf

- Are the workstations/work-activities designed to prevent use of repetitive or high frequency exertions?
  Yes/No/ Not Applicable
- Are the employees prevented from using same equipment/workstation continuously for >= 4 hours per day?
  Yes/No/ Not Applicable
- Do you have policy that prevents workers from lifting, pushing, pulling heavy loads?
  Yes/No/ Not Applicable
- Do you provide annual or bi-annual safety or ergonomics training?
  Yes/No/ Not Applicable
- Do you have policy that ensures job rotation?
  Yes/No/ Not Applicable

3.2 Psychosocial and psychophysical exposure

- Do the employees frequently complain about work-related stress due to the social work environment (social support, relationship with supervisor, colleague, etc.?)
  Yes/No/ Not Applicable
- Do you have policy that encourages/trains the employees on maintaining healthy work-life balance?
  Yes/No/ Not Applicable
- Do you provide annual or bi-annual stress management training?
  Yes/No/ Not Applicable
- Is it easy for the employees to take time off during work to take care of personal or family matters?
  Yes/No/ Not Applicable
- Do you have trade union that represent/protect workers interest?
  Yes/No/ Not Applicable
- Do you have policy that encourages employee participation in day-to-day decision making?
  Yes/No/ Not Applicable

- Do you have policy/mechanism (suggestion box, complain box, employee counselling, etc.) that promotes healthy work environment?
  Yes/No/ Not Applicable
- Do you promote regular outings/games/fun activities/team building exercises among employees?
  Yes/No/ Not Applicable

3.3 Environmental exposure

- Do the employees frequently complain about work-related discomfort or stress due to physical work environment (noise, illumination, climate, etc.)?
  Yes/No/ Not Applicable
- Do you routinely conduct survey to monitor employees' noise exposure?
  Yes/No/ Not Applicable
- Do you routinely conduct survey to monitor employees' vibration exposure?
  Yes/No/ Not Applicable
- Do you routinely conduct survey to ensure that the workstations/work-activities do not have excessive illumination/glare issues?
  Yes/No/ Not Applicable
- Do you provide sufficient sizes/options for all the necessary personal protective equipment (PPE)?
  Yes/No/ Not Applicable
- Do you have policies to prevent slipping/tripping hazards?
  Yes/No/ Not Applicable
- Do you have after work housekeeping policies to ensure that the workstations are maintained neat and clean?
  Yes/No/ Not Applicable
- Are the mechanical ventilation systems in good condition and regularly maintained so that employees do not get exposed to dust, fumes, and gases?
  Yes/No/ Not Applicable
- Do you have policy that prevents outdoor work under severe weather condition without proper protection?

Yes/No/ Not Applicable

3.4 General Policy

- Do you maintain emergency response plan?
  Yes/No/ Not Applicable
- Do you have a procedure for recording work-related incidents and near misses?
  Yes/No/ Not Applicable
- Do you have policy that enforces routine review of all the reported incidents and near misses?
  Yes/No/ Not Applicable
- Do you routinely provide training on health and safety regulations relevant to your plant?
  Yes/No/ Not Applicable
- Do you have policy that enforces regular maintenance check-up?
  Yes/No/ Not Applicable
- Do you have policy that enforces adequate machine guarding?
  Yes/No/ Not Applicable
- Do you have competent persons trained to ensure the safe evacuation of all persons from buildings in the event of serious and unexpected events (fire, cyclone, tornado, etc.)?
  Yes/No/ Not Applicable
- Do you have policy in place to treat workers in an event of emergency/accident?
  Yes/No/ Not Applicable