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A Review: Implementation LCSA Method to Achieve Sustainable Supply Chain in Sugar Production

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ABSTRACT

In today's rapidly evolving world, every industry grapples with challenge of integrating sustainability into supply chain process for survival and prosperity. Manufacturing significantly influences sustainability, affecting economy, environment, and society. The manufacturing industry significantly contributes to growth and development of any country. Manufacturing is grappling with increasing environmental, governance, and sustainability challenges to ensure growth and survival in an unpredictable business and environmental environment. The literature on sustainability of economy and environment of a manufacturing industry is extensive, but social sustainability aspects have received less attention. This study selected sustainability indicators based on discussions with practitioners and existing literature. This research's focus is to oversee Life Cycle Sustainability Assessment (LCSA) of sugar manufacturing process. To assess effects of society, economy, and ecology of products, LCSA integrates three separate methodologies: Life Cycle Assessment (LCA), Life Cycle Cost (LCC), and Social Life Cycle Assessment (SLCA). LCSA is a theoretical instrument in sustainability science that incorporates sustainability across board in production. The research findings will provide valuable insights for practitioners, researchers, and managers on potential methods for implementing sustainability in sugar manufacturing.

1. Introduction

In industrial world, increasing competition demands a strategic approach to meet customer demands for affordable, high-quality products. This requires all actors in supply chain, from upstream to downstream, to ensure successful competition [1]. Sustainable development is crucial due to global challenges of ecology and society. Corporations are actively focusing on assessing and enhancing product sustainability. Sustainable development is still in its early stages in developing nations [2].

Reuse, recycling, and remanufacturing, which have proven effective in rich nations, remain most promising approaches to solving environmental problems in developing nations [3]. To address environmental concerns, many companies/organizations have started to adopt what is termed 'eco-

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design' and 'green design', these strategies relate to investments in green design programs [4]. Green design, which takes into account all of product life cycle in objectives in environment, health, safety and sustainability, is interpreted as a systematic approach to designing performance [5]. [4] Defines supply chain integration capability as, a group of supply chain skills, knowledge, and competencies that are developed over time through complex interactions. Product recovery is typically done in informal sector without modern infrastructure [6]. Because poor waste management methods can alter socioeconomic connection between ecosystems and human well-being [7], companies frequently amplify existing environmental issues (e.g., pollution, trash). Life Cycle Sustainability Assessment (LCSA) is one technique to evaluate sustainability that takes all three of these factors into account. Three separate methods— Life Cycle Assessment (LCA) to analyze the effects in environment, Life Cycle Cost (LCC) for determining a product's monetary worth, and Social Life Cycle Assessment (SLCA) for analyzing its societal effects—combine to form LCSA [8].

LCA is useful to determine the quantitative impact in environment of products, assess and compare multiple processes for their environmental consequences, and discover opportunities for process and product development. In addition, LCC approach takes into account expenses incurred from time of a product's inception all way through its eventual decommissioning [9]. And SLCA technique is used to measure implementation of social in a company by using Level of Social Sustainability and distributing questionnaires to employees in company.

LCSA, a theoretical tool in sustainability science, incorporates environmental considerations into every stage of manufacturing. Product decisions are informed by criteria relevant to sustainable development. Sala [10] investigated LCSA to show its efficacy for a thorough assessment, emphasizing significance of systemic sustainability in production, and found that while certain adjustments are needed to address all areas of sustainability, LCSA has proven its success. An emerging field of study with promising social and economic ramifications is LCSA method. Unpredictability, subjective in weighting, double count, and divergent perspectives from economy are all obstacles to be overcome. Competition amongst sugar factories arose in context of rising productivity to meet market demand as sugar business expanded. However, better care must be taken of environment in addition to boosting productivity and efficiency. The current industrial and social economies are also impacted. Industry's future contributions to employment and living standards make it a crucial cog in economic and social system.

The sugar industry is one of largest in world. supply of sugarcanes is sole determinant of sugar industry. Because of this, sugar companies are only found in cane growing regions, typically within a 25 km radius of sugarcane farms. According to Ramjeawon [11], Sugarcane's cultivation occurs primarily in tropical countries. It is a large grass with strong roots [12,13]. In 2009-2010, globe produced 1683 million metric tonnes of sugarcane, or 22.4% (weight) of all agricultural output. Global sugar output and consumption from 2000-2001 to 2009-2010. When it comes to sugarcane production, Brazil and India are first and second, respectively. However, 275,000,000 metric tons of sugarcane are produced by each of them. India is the top 2 largest sugar producer in the world, as reported by Macedo (1998) [14]. India's 12 million metric tons [15] annual sugar output comes from its more than 430 sugar mills. As a vital part of foods we eat, more than 40% of global sugar making, was concentrated in Thailand, India, China, Brazil and Australia. There are about 115 countries that produce sugar. There are 67 that use sugarcane, 39 that use sugar beets, and 9 that use both, as reported by Lichts (2007) [16]. That is to say, according to Contreras *et al.*, (2009) [12], sugar is produced using sugarcane 70% of time and other crops 30% of time.

The first literature to address idea of LCSA was written more than a dozen years ago. Since then, there have been many papers showcasing various LCSA techniques. But there is currently no established LCSA methodology, and suggested assessment methodologies differ. This serves as inspiration for study, which analyzes pertinent LCSA literature and provides an outline of field's current level of development in context of sugar production. summary will serve as a foundation for more scientific research in this field. The diversity of LCSA literature already in existence and short length of this paper force planned research to be narrowly focused. Because of this, and in an effort to contribute to sustainable manufacturing, manufacturing is very relevant to global sustainable development.

2. Methodology

A lack of cohesion between related disciplines is one of major obstacles to meeting aforementioned research needs and challenges, review of literature published between 2014 and 2023 using title, abstract, or keywords from sciencedirect (Life Cycle Sustainability Assessment, sustainable manufacturing). Because this is a review journal, we integrate three methods the sugar industry can apply: LCA, LCC, and SLCA. Because in the previous journal, there was still no one to discuss the complexity of these three methods in the sugar industry. The resulting list of 105 papers was narrowed down to include only those that included case studies. To accommodate for recent modifications to LCSA method, the emphasis has been on publications from the previous seven years (since 2016), deleting 34 case studies. To make a meaningful contribution to field of sustainable manufacturing, we excluded those case studies that did not specifically address sugar producing region from our final study. Before label "Life Cycle Sustainability Assessment" was ever coined, in 2003, Klöpffer [17] argued in favor of uniting LCA, LCC, and SLCA. term "LCSA" appeared for first time in print in a 2007 article by Zhou [18]. There have been subsequent literary occurrences using alternative definitions. Guinée [19] describes LCSA as a multidisciplinary approach to integrating models. Decision-making that takes into consideration factors in economy, environment, and society to make more long-lasting products is called life-cycle analysis is referred to as LCSA in UNEP/SETAC standards. Klöpffer created a theoretical formula for LCSA in 2008 [17].

$$LCSA = LCA + LCC + SLCA \quad (1)$$

The environmental effect of products' life cycle shall be considered by LCA in accordance with ISO standards (e.g., air emissions, water contamination). LCC is a technique for assessing impacts in economy (such as costs and profits) and is also to some extent standardised. The assessment of social implications (such as a fair wage or working hours) is made easier by SLCA. There is no uniform standard, in contrast to LCA and LCC. However, UNEP/SETAC created standards for conducting SLCA in 2009. same is true with LCSA, which combines all three approaches. LCSA guidelines were released in 2011 [21]. These recommendations state that stages for conducting an LCSA are as follows: Definition of objectives and scope; Analysing the life cycle; Evaluating life cycle's effects; and Finally, Determination of life cycle's meaning. The fact that this is already basis for LCC and SLCA procedures provides sufficient justification for this.

However, there are particular difficulties with utilising LCSA because of complicated alternatives, wide range of necessary criteria, and uncertainties: majority of decision-making situations have goals that are in conflict with one another, many indicators are represented in various units, and performance evaluation data are ambiguous [22]. However, there is no established process for carrying out LCSA. For instance, LCC, LCA, and SLCA system boundaries must be consistent (preferably identical). This is something that Klöpffer [17] emphasises. overall LCSA system boundary, in contrast, is what UNEP/SETAC suggests include all relevant unit processes, which may result in different system bounds across dimensions. literature analysis that is proposed here is motivated by LCSA's varied and poorly developed methodology [23].

[35] Majority of reviewed papers highlight Lean concept's connection to environmental sustainability, reducing waste, pollution, energy use, and fuel consumption, while also minimizing ecological impact of their products and processes. Social component can help businesses become socially responsible or express themselves through secure products for workers and customers. It is considered a means of establishing ethical standards for both society and its workforce. Two primary perspectives on economic side of sustainability today are achievement of corporate financial goals or development of economic value through Lean. Four out of seven articles, including Wong and Wong (2014), Glover *et al*., (2015), and Ali *et al*., (2013), focus on defending sustainability. To maintain long-term performance, many companies must focus on this specific issue. This paper emphasizes significance of people. With assistance of top management, employees should be handled efficiently (Wong and Wong, 2014) and supported in their learning and development (Ali *et al*., 2013; Glover *et al*., 2015) as part of organization's overall cultural transformation. Alves and Alves (2015) also emphasised need for sustainable development to strike a balance among operating objectives, respect for human rights, and environmental preservation. Item under consideration claims that there are still many difficulties involved in adopting sustainability into a firm. It is believed that businesses like these, which lack alignment with operations management objectives, are main obstacles to implementing sustainable initiatives (Alves and Alves, 2015). Just-in-time is one lean tool that could conflict with green goals, claim Cherrafi *et al*., (2016). Verrier *et al*., (2014) elaborate on demands that corporates must conquer prior to successfully implementing sustainability, pointing to budgetary constraints, immaturity of current technology, and a lack of general awareness. Using LCA techniques to evaluate a positive or negative environment for industrial uses is still legal at time. However, additional examination of LCC and SLCA for sectors that affect LCSA is required. Table 1 shows the Summary of factor of sustainable manufacturing (R. Siegel et. al, 2019).

Table 1
Summary of factor of sustainable manufacturing (R. Siegel *et al.,* 2019)

Author	Environmental aspects	Social aspects	Economic aspects	Sustainability	Other sustainability factors	Difficulties of integrating sustainability
Africa Cherrafi *et al*., (2016)	Products manufactured in a manner that minimizes their consumption of resources from nature and their environmental effect.	Products that are secure for workers, customers, and communities	Products with a high profit margin	N/A	Comprehensive perspective of the complete manufacturing and supply chain systems	It's possible that some lean concepts conflict with sustainability. such as Just in time

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Author	Environmental aspects	Social aspects	Economic aspects	Sustainability	Other sustainability factors	Difficulties of integrating sustainability
Ali *et al.,* (2013)	N/A	N/A	N/A	Management directs employee behavior toward innovation and motivates through learning and skill development, whereas a strategic lens emphasizes individual and group to use corporate purpose in prioritizing improvement efforts.	Product design, product end-of-life, manufacturing by-products, end-of-life recovery, and product life extension, should all be included in the process, which goes beyond the core of OM.	When human resource capabilities aren't in sync with operational management plans, maintaining operations becomes a higher priority.
Asia Wong and Wong (2014)	The environmental welfare is a crucial aspect of human life.	The statement enhances the overall well-being of individuals.	The company ensures the continuous commercial success by creating value to stakeholders.	Effective employee management is crucial for achieving high performance and achieving lean objectives, ultimately leading to sustainable operations.	Product end-of-life, manufacturing by-products, product design, product life extension, and recovery operations are all examples of OM-related concerns that should be factored into the process.	When human resource capabilities aren't in sync with operational management plans, maintaining operations becomes a higher priority.
Europe Verrier *et al.*, (2014)	The goal of stricter environmental regulations is to cut back on trash production, energy use, and raw material usage.	A new way of thinking about production should put the social dimension at the forefront because it is being blatantly ignored.	Consideration should be given to financial gains resulting from lean actions.	N/A	Depending on the culture or how resources are used to make high-quality items.	Expenses and corporate priorities. Existing tools haven't been modified yet, aren't always mature enough, and frequently aren't acknowledged by industry.

Author	Environmental aspects	Social aspects	Economic aspects	Sustainability	Other sustainability factors	Difficulties of integrating sustainability
Garza-Reyes (2015)	reduction of the organization's negative ecological effect and increased operational environmental efficiency	N/A	attaining organisational budgetary goals	N/A	Elimination of waste across the board for manufacturing, design, factory operations, and supplier networks	More research is needed on the composition, efficacy, use, and practical implications of various parts.
North America Glover *et al.,* (2015)	N/A	The text focuses on the relationship between value and culture.	N/A	In order to adapt to shifting market conditions, management at this company is encouraging employees to keep an open mind, reward and recognize those who show loyalty and commitment to the organization, recognize the importance of non-monetary aspects, and encourage growth and responsibility.	N/A	N/A

Author	Environmental aspects	Social aspects	Economic aspects	Sustainability	Other sustainability factors	Difficulties of integrating sustainability
South America Alves and Alves (2015)	Reducing pollution and waste output during production to have a sustainable environmental impact	Establishing ethical standards for the community, partners, and employees	Economic value produced by the company through profitable ventures to satisfy the needs of shareholders or to improve the neighbourhood and society economically	Organisational cultural change is needed to sustain gains over time. Senior management support for fostering the growth and development of employees through modifying attitudes, values, behaviour, and organisational structure	Sustainable development is a thoughtful balancing act between economic viability, human dignity, and environmental protection. Provide work that is safe for the company by making good use of its materials and avoiding waste.	People are the biggest obstacle to sustained business. It is very difficult to fulfil the objective of running operations even if staffing levels are below what was anticipated by OM.

2.1 Sugar Producing Materials

For human consumption, sugar is a necessity. Sugar is primarily made from sugarcane, which is typically grown in tropical climates. Probably all green plants have sugars, which are a substantial source of carbohydrates. Most fruits and vegetables also contain significant amounts of sugars. Sucrose, fructose, and glucose are three most common types of simple sugars. Sucrose is a sugar that can be broken down in body into two simpler sugars, fructose and glucose. [13].

Sugar is extracted from several plants including sugarcane, corn, sugar beets, and cassava. However, sugarcane is still preferred technique of production in vast majority of countries due to a number of reasons, including overall cost, environmental implications, sugar production rate, and proportion of sucrose included in distinct substance. According to Renouf *et al.*, (2008) [24], sugar mostly yields three different types of juices:

i. After grinding and clarifying, 93% pure sugarcane juice is produced.
ii. Sugar beet juice is made from diffusing sugar beets, followed by purifying them (92% purity).
iii. a mixture of maize hydrolysate is made from saccharificating (hydrolysis) and filtrating them (95% purity).

2.2 Sugar Industry

Earlier, sugar business typically produced solely sugar, but today it also includes sugar mills, power plants, distilleries, etc. that produce sugar [13]. Fig. 1 depicts common design of sugar business.

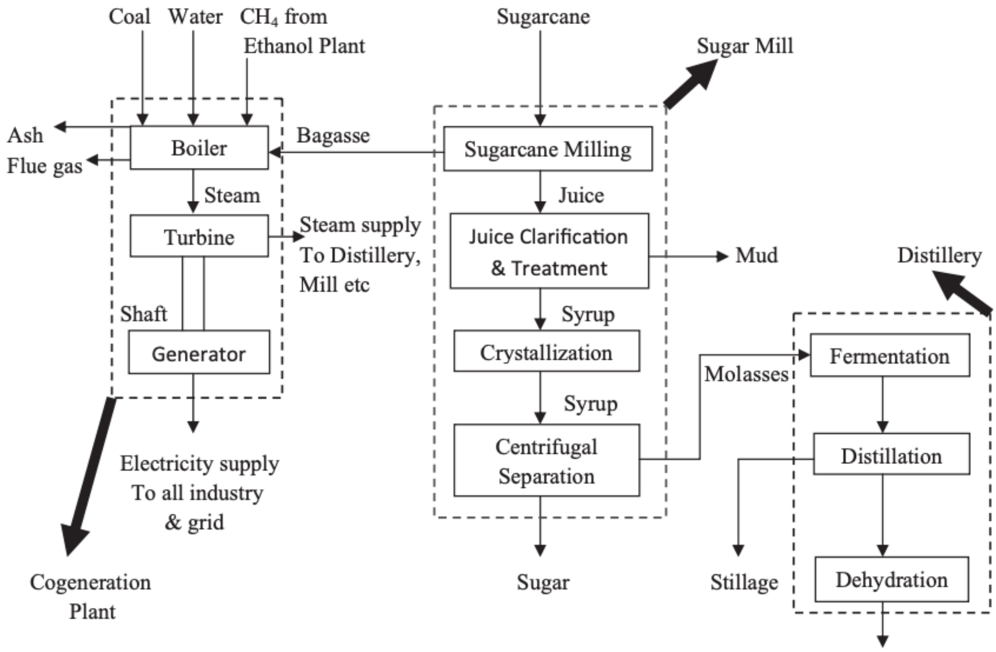

Fig. 1. General layout of sugar business

2.2.1 Sugar mill operations

The following techniques are applied in sugar mills to manufacture sugar [25].

i. Milling of sugar

To start, sugarcane is washed to get rid of extra dirt, rocks, and garbage. After being cleaned and fibrized, sugarcane is then run through a number of different mills that are connected in sequence process of obtaining raw juice and bagasse. Both of these things are stored separately. Both bagasse used to generate electricity and raw juice that needs to be clarified and processed are sent to a cogeneration facility.

ii. Juice treatment and clarity

Some non-sugar pollutants, including as sulphur and lime, are found in raw juice and are removed through a chemical process. For chemical processes to take place in juice, juice must be heated. Chemical methods are used to divide fresh juice into two. first is liquid, whereas second is solid. Mud or filter cake refers to solid phase, whereas syrup describes liquid. Juice is separated into syrup and dirt by clarifier.

iii. Crystallization

The steam generated from bagasse is then used to boil clarified juice or syrup, reducing water content and transforming it into crystal form. Syrup's concentration of sucrose will increase as its water content decreases.

2.3 Waste by Sugar Production

Molasses and bagasse, two sugar industry byproducts, are both useful to other plants. Ethanol plants employ molasses and bagasse as their primary materials. Bagasse and molasses are byproducts of sugar production that can improve sector's green reputation. Fuel, paper, energy, and organic chemicals are all produced using byproducts from sugar industry. With goal of reducing CO2 emissions and associated need for process steam to do. So, it is crucial to produce excess power using biomass, bagasse, and waste as fuel [25].

2.3.1 The bagasse

Despite its status as a waste product, sugar industry puts bagasse to good use in power plants. Bagasse and eucalyptus are burned to generate electricity for sugar factories in Nicaragua. During sugarcane season, bagasse is favored over eucalyptus, whereas opposite is true during rest of year. According to Broek (2000) [26], bagasse is a beneficial byproduct for producing heat and electricity. Bagasse, a by-product of sugar mills, typically contains 2% sugar that is burned to produce steam and power, 50% fiber, and 48% moisture. Compared to creation of oil and coal-based electricity, generating electricity from bagasse has more benefits for environment [27].

Kiatkittipong [28] explored following four options for using bagasse:

i. Using landfill gas while disposing of waste.
ii. Biogas generation and anaerobic breakdown in a reactor.
iii. Burning waste to create electricity.
iv. Pulp manufacturing.

Bagasse is used as an input material in pulping process to make paper. Methane gas is created during landfilling and used to generate electricity. Additionally, bagasse is used directly to produce electricity. Methane gas is also produced during anaerobic decomposition in order to produce power, but this process occurs in a tightly regulated reactor. Therefore, bagasse's anaerobic decomposition proceeds more quickly than it would in a landfill and provides highest environmental performance compared to alternative options. With exception of photochemical oxidant potential, among four methods, incinerating bagasse for energy generation had least negative impact on environment. [28].

2.3.2 Molasses

Molasses is indeed a byproduct of sugar industry, and essential ingredient in distillation of ethanol. Ethanol shall be tested once it has been made from sugar cane, or indirectly from molasses which is byproduct of a sugar industry [30,13]. To produce ethanol (C_2H_5OH) and carbon dioxide (CO_2) from sucrose ($C_{12}H_{22}O_{11}$), yeast is used in fermentation step [31]. Ethanol has a lower heating value (LHV) than regular gasoline (CG), but it burns more efficiently, thus difference is negligible [29]. Sugarcane has traditionally been used to produce bio-ethanol in Brazil, but bagasse has replaced it in recent years. At present, bagasse is used to make ethanol rather than being burned to provide heat and electricity. It takes 30.1 kilograms of sugarcane to produce 1 kilogram of ethanol, while only 12.6 kilograms is required when both bagasse and sugarcane are utilized in process. When considering

GHG emissions, however, LCA suggests that converting bagasse into power rather than ethanol is most environmentally friendly option [32].

3. Conclusion

3.1 LCA Environment

The data clearly points in direction of optimizing how sugar industry disposes of its rubbish. One of most important resources for manufacturing is electricity. Sugarcane, principal crop used in sugar production, is typically cultivated in tropical climates. Even though molasses and bagasse are waste products in sugar industry, they are put to good use by other crops. Sugar refineries, distilleries, cogeneration plants, plant residents, and grid-supplied electricity for sale all utilize steam and electricity produced from bagasse in cogeneration facilities. Eucalyptus, together with coal, rice husk, and CH4, is used to generate electricity in countries without a robust sugar industry. A multifuel boiler is thus essential for a cogeneration facility [13].

[13] Molasses is another byproduct used by distilleries to create ethanol. Distilleries produce ethanol and discard stillage as byproducts. To produce electricity, cogeneration systems use biogas and CH4 generated by anaerobic digestion of waste in the UASB reactor. Sugarcane fields are among many agricultural areas that benefit from use of filter cake, also known as ash, a byproduct of sugar production. Waste is also produced from sugarcane byproducts such as stalks, leaves, and husks.

Mills use them as a source of biomass feedstock. The sugar industry is responsible for utilizing some materials and production of some by- and end-products. Environmental problems like eutrophication, acidification, and global warming are directly influenced by sugar industry's discharge of different harmful chemicals and solid particles into air and water.

3.2 Life Cycle Cost

Life cycle costing can be minimized by cutting operational and maintenance costs. Maintenance costs can be reduced and output increased by implementing cutting-edge technology like oil and gas management software, Internet of Things (IoT), and anti-corrosion technologies. Implementing a circular economy that reuses the bulk materials used by the supply chain might reduce raw material costs. A rise in income as a result of greater staff productivity will also contribute to a reduction in total costs [33].

3.3 Social LCA

The industries' obligations to 'workers' who make up stakeholder base include ensuring their workers' excellent health and safety, giving them necessary training, and paying them fairly. To treat contract workers equally with permanent employees in industries, stricter standards must be implemented. Industries must regularly solicit feedback from their 'consumers' for stakeholder 'consumers' and respond appropriately to that feedback. Consumer education initiatives on environmental issues must be organized. Industries should support diverse technological and economic developments for stakeholder "society" and run initiatives to raise public knowledge of "sustainability issues" for society [34].

The sugar industry, primarily based in tropical climates, generates significant waste products such as sugarcane, molasses, and bagasse, which are used in various industries such as sugar refineries, distilleries, and cogeneration plants. These waste products are also used to produce ethanol and biogas. The industry's waste contributes to environmental issues like eutrophication, acidification, and global warming. To minimize costs and improve efficiency, the industry should implement cutting-edge technology, such as IoT and anti-corrosion technologies, and a circular economy. Additionally, industries should ensure workers' health and safety, provide necessary training, and pay fairly. Stricter standards and consumer education initiatives are also crucial for a sustainable industry.

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