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Antecedents for Circular Economy in Sugar Industrial Ecology in Emerging Economy

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ABSTRACT

Sugar industrial ecology involves the efficient reuse, recycling, and repair of byproducts, employing advanced technologies to foster the development of sustainable urban environments. Once known for its detrimental impact, the sugar factory needs to look into the circular economy and the procurement of byproducts. Therefore, the study attempts to answer the research question – What are the antecedents for a circular economy in the sugar industry in the emerging economy? This research delves into the circular economy practices within the sugar industrial ecosystem, utilizing a comprehensive analysis of input-output relationships and structural aspects. Data collection involved a combination of secondary data and insights from focus group discussions with eight key officials representing the top eight sugar factories. The analytical approach encompasses multiple regression and descriptive statistics to extract meaningful insights from the secondary data. A key revelation is the significant role by-products play in creating construction materials such as cement, bricks, paver blocks, and activated binders. Utilizing secondary by-products from the sugar industry in manufacturing these materials mitigates the construction sector's carbon footprint and enhances the final products' quality. The study also signifies procuring sugarcane and other byproducts for sugar, ethanol, and electricity generation. It highlights the transformative potential of embracing sustainable practices within the sugar industry, demonstrating how such initiatives can positively impact the environment and the quality of goods produced in related sectors.

1. INTRODUCTION

The sugar industry is the largest agro-based industry after the cotton textile industry. According to the data in the report of Niti Aayog, the world has a sugar production of 1723.6 lakh tonnes. Brazil and India are the top countries contributing significantly to sugar production. Brazil produced 358 lakh tonnes of sugar, and India produced 272.5 lakh tonnes of sugar [1]. The sugar industry in India has provided livelihood to five crore farmers and five lakh workers by employing them in the mills. The sugar industry has provided livelihood opportunities to rural populations [2]. According to the Essential Commodity Act of 1955, it has been found that sugar and sugarcane are categorized as essential commodities. The sugar industry is well known for producing different types of sugar, namely regular, extra-fine, fine sugar, fruit sugar, bakers special, ultrafine sugar, confectioners powder sugar, and coarse sugar with several byproducts like bagasse, molasses, ethanol, fly ash, and pressmud [3]. If left unused, these byproducts have an adverse impact on the environment. In the past, the sugar industry has been classified under the red category - the most polluting industry in India [4]. This has led to an increase in pollution and environmental and water distress. Since then, the sugar industry has been focusing on reusing the byproducts from sugar production. Research has been conducted on different approaches and strategies for reducing, reusing, and recycling the byproducts as waste obtained during sugar production. There have been studies where recycling and reusing the byproducts have been discussed, but the linkage with the circular economy is still at a nascent stage. The research gap indicates that though the byproduct reuse in the sugar belts has been in practice, there is a scope to explore as the sugar industry produces a lot of byproducts. The antecedents for a circular economy in the sugar industry are also yet to be explored. Therefore, the research drives the need to study the circular economy for the sugar industry. The study derives the research question - what are the antecedents for circular economy in the sugar industry? Driven by the research question, the study aims to understand the status of the sugar industry in a sugar belt and explore the antecedents for circular economy in sugar industrial ecology.

To conduct the study, we have focused on the 3Rs (reduce, reuse, and recycle) as the 3Rs in the sugar industrial ecosystem lead to the circular economy. A circular economy in the sugar industry is a significant contribution toward sustainability [5]. The study adds different perspectives on the circular economy in the sugar industrial ecosystem. The role of the sugar industrial ecosystem is explained through the structured input-output analysis used in the paper, and it concludes that it has significantly contributed to the circular economy. The study develops a model for the circular economy based on the input-output analysis and focus group discussion (FGD). The structural analysis is based on the focused group discussion with eight officials of the sugar industry. The output of the structural analysis has helped in understanding the usage of different byproducts of the sugar industry.

The paper is organized into six sections. The next section discusses the sugar industrial ecology, followed by the input-output analysis, circular economy in sugar industrial ecology, and research gaps. Section 3 deals with the research methodology aspects used for the study, followed by the segment of results and discussions. Section 5 explores the implications of the study followed by conclusion and scope for future research. Section 6 explores the implications.

2. LITERATURE REVIEW

This section demonstrates the ongoing research and developments in the field of industrial ecology and circular economy. The review also focuses on a comparative analysis or critique of the existing literature. The literature review explicitly identifies research gaps.

2.1 Sugar industrial ecology

Sugar industrial ecology refers to the reuse, recycling, and repair of byproducts with the proper implementation of technologies for developing a sustainable city [6]. In their paper balanced sugarcane industry, [7] conclude that sugarcane is a green and sustainable industry that tries to come down to zero waste, which may not be possible in the lifecycle. However, the by-product of the sugar industry is helpful for balanced ecology if it refers to sugarcane waste resources as raw materials for many industries instead of burning them and throwing them in open garbage. The sugar industry ecology is concerned with the reuse of all byproducts [8]. Byproducts produced by the sugar industry are pressmud, bagasse, molasses, filter cake, furnace ash, pith, hot bottom ash, and wastewater [9]. Many times, these byproducts, if left unexposed, lead to an imbalance in the natural ecosystem. Fito et al. [10] in their paper on Ethiopia, suggest that the sugar industry and ethanol production process distilleries produce wastewater that affects the biological and microbiological structures when discharged into the natural environment. Hence, it advises the environmental legal framework to monitor and reduce causes that hamper ecological characteristics. This has led to the evolution of the concept of sugar industrial ecology. Sugar industrial ecology is the reuse, recycling, and repair of the byproducts of the sugar industry. This leads not only to economic sustainability but also to social and environmental. These properties indicate that if the effluents are not properly treated before being discharged into the environment, they may adversely affect aquatic and terrestrial ecosystems. Table 1 shows the alternate use of the byproducts from the sugar industry.

Table 1. Reuse and recycle the sugar byproducts

Byproducts of Sugar	Reuse and Recycling
Molasses	Methylated spirit, cattle food, production of yeast, fertilizer, road surface, fuel, cheap confectionary, blending purpose, alcohol for power in partial substitution of petrol, ethanol, and spirit beverages
Bagasse	Paper
Filter cake	Composting, cement
Furnace ash	Treatment of metal industrial wastewater
Fly ash	Treatment of metal industrial wastewater
Industry wastewater overflow	Composting, water conservation, repatriation of nutrients to the soil
Pith	Scrubber
Hot bottom ash	Lagoon used in road construction

Source: Kumari, 2017

2.2 Input-output analysis

Input-output analysis helps in the circular economy, including the quantity and price models [11, 12]. It originated in 1955 in Japan [13]. Input-output analysis works on waste generation and waste consumption [14]. The input-output analysis helps model the nutrients and energy flow [15]. There are two types of input-output analysis as shown in Figure 1.

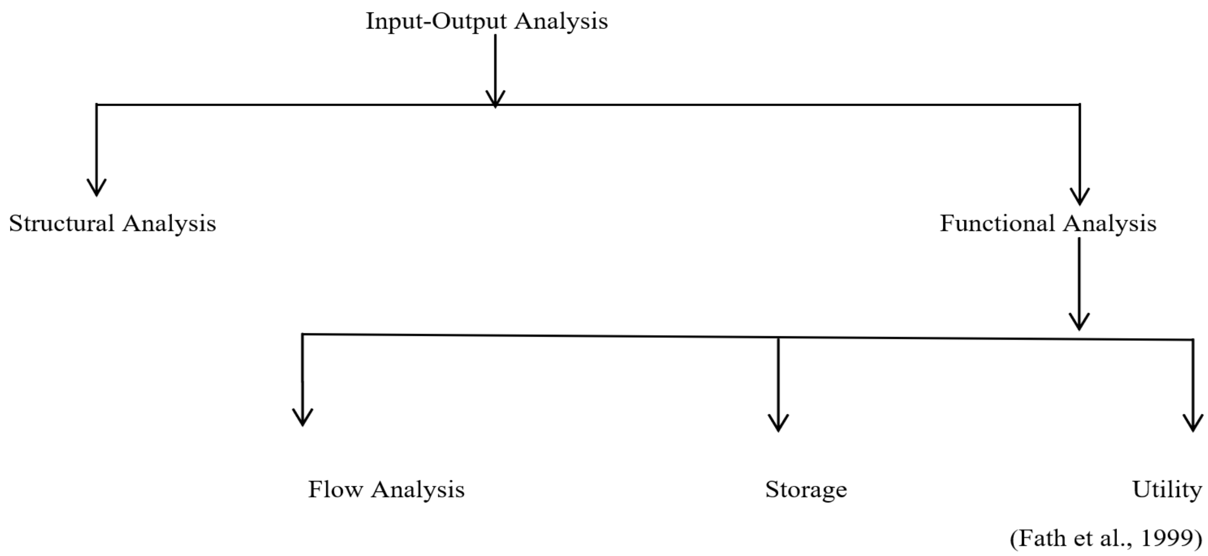


Figure 1. Types of input-output analysis

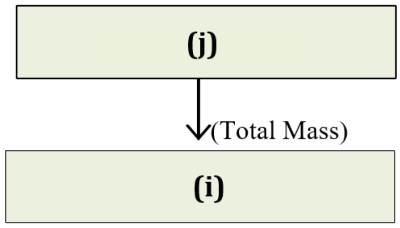


Figure 2. Flow analysis

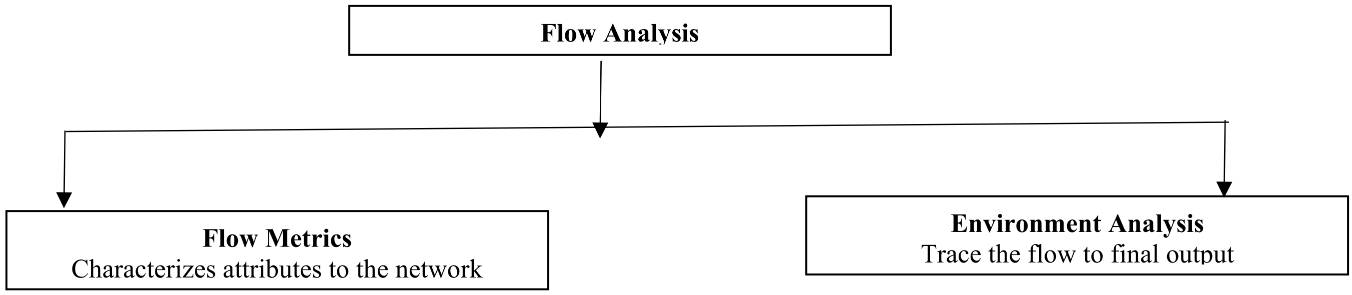


Figure 3. Tools of flow analysis

Structural analysis is concerned with the presence and absence of connections within the organism and the process. Adjacency Matrix is obtained with the help of structural analysis of input-output.

Flow analysis of input-output predicts the flow of products more closely than structural analysis (Figure 2). Monetary flow is replaced by mass flow from process j to process i and is normalized by the total flow to process i.

Tools of flow analysis: there are two flow analysis tools shown in Figure 3.

Input-output analysis helps in linking sustainability, namely economic, social, and environmental, since it allows a linkage of biophysical and social data with economic or monetary terms [16]. Input-output analysis is an empirical tool derived by Leontief [17] in the late 1930s. Input-output equations can be used for analyzing policies for modeling systems for energy and climate-related studies [18]. The input-output model allows for information regarding energy and environmental pressures. The economic input-output analysis has been developed by Ardent et al. [19].

2.3 Circular economy in sugar industrial ecology for sustainability

The sugar manufacturing process has stages generating pollutants in different forms like wastewater, solid wastes, and air pollutants. Sugar industry ecology is not just the production of sugar but also the production of several sources of energy, electricity, and other products. A recent study by Meghana and Shastri [20] reviewed the fundamental aspects of sugarcane processing and techno-ecological assessment and stated that the sugarcane sector is ennobled by technological innovation. However, it is missing and has more scope to work on value-added chemicals that come out in the process of sugar production. In addition, Manavalan and Jayakrishna [21] address the importance of Industry 4.0 for a circular economy where the effective management of waste material is a source of energy that empowers the circular economy segment in the extent of social and economic development. Further, it highlighted the importance of technology in circular economy in view of sustainable and ecological development perspectives of waste resources and recycling. However, agricultural waste resources are substantial and connect with natural ecosystems that concur effective progress in the economy and environment in the flow of fostering waste and energy recycling resource industries [22].

The sugar industry faces a lot of environmental challenges in the form of land degradation, high water consumption, air pollution, and the loss of biodiversity. It is also responsible for an increase in inequality in the rural sector. The need for sustainability evaluations for the sugarcane biorefineries has been emphasized especially in developing economies where the ideas of circular economy have not been fully focused upon [23]. India is the second largest producer of sugar in the world. The sugar industry in India has witnessed several innovations in technology, allowing it to meet the ever-increasing demand for sugar and the various value-added products that can be obtained by transforming the wastes from the industry. Today, technological interventions have allowed the Indian sugar industry to develop improved varieties of crops, good quality seeds, profitable intercropping systems, and engage in bio-intensive activities, nutrient management, increase in the water availability with the improved irrigation system, and mechanization of the industry. Solomon et al. [24] identified sugarcane as a beneficial crop for its utilization in the production of sugar as well as the creation of renewable sources of energy. A detailed examination showed that green energy resources like ethanol and compressed natural gas (CNG) can help make the Indian sugar industry more diversified.

2.4 Research gaps

The literature review has discussed the aspects of the circular economy in the sugar industry (Table 2). Though the Indian sugar industry has moved towards circularity, it lacks steps to adopt mechanization to drive towards efficiency along with sustainable development, as India is about 40% below its average potential in the case of mechanization. The area is evolving; therefore, there is a need to discuss the antecedents of a circular economy in the sugar industry. The key research gaps have been tabulated in Table 3 from the recent literature.

Table 2. Circular economy in sugar industry and sustainability

Factors	Descriptions	References
Economic Sustainability	Cost towards the environment, supply chain, and raw materials	[25-27]
Environmental Sustainability	Recycling and pollution management	[26-31]
Social Sustainability	Impact on society, customers, employees, and management commitment	[27, 32, 33]

Source: Authors' calculation i.e., compiled for available factors

Table 3. Research gaps from the recent literature

Refs.	Research Gap
[34]	Indian sugar mills produce a large volume of agro-waste sugar cane bagasse (SCB), which, due to its improper use, causes environmental issues. Contrastingly, the valorization of SCB by integrating advanced technologies for biochemical production can alleviate waste disposal problems, enhance resource utilization, and promote a circular economy.
[35]	Sugarcane processing in the sugar industry generates vast amounts of waste, which can be valorized into biofuels and value-added chemicals based on the circular economy concept.
[36]	With time, the second generation of biofuels will play a crucial role in the energy scenario in years to come. However, India, with its abundant source of renewable energy, lacks a proven technology that is cost-effective for biomass bioconversion.
[37]	The sugarcane industry presents environmental problems since it generates large amounts of waste that is normally valued energetically in sugar mills. However, growth in the industry has also led to increased waste production, making it impossible to discharge the quantities generated. The low density of the material, associated with other problems common to biomass, such as fermentation of the product, makes export very difficult and costly.
[38]	By outlining and analyzing the primary barriers in the sugarcane ethanol industry, this study's findings improve the field of knowledge in the circular economy. Economic and financial constraints were the main problems in adopting a circular economy. Future studies can expand our understanding of the theme by examining the obstacles to accepting the circular economy.
[39]	Low amounts of ethanol were produced per mass of raw feedstock under conditions that maximized furfural output due to yeast inhibition brought on by the breakdown of cellulose, organic acids, furans, and pseudo-lignin. Furfural residues at low severities resulted in higher ethanol yields, while the corresponding furfural yields fell short of industrial outputs.
[40]	Improving bio-jet fuel hydrocarbons' yield by upgrading even the C4-C7 high-carbon alcohols in light alcohols to synthesize C8-C16 high-carbon alcohols.
[41]	Molasses can get contaminated easily, and hence, there is a need to look for new strategies that can be used to build bioconversion processes, which would also reduce the cost of production. There should also be a search for other applications where the molasses could produce more value-added products.
[42]	Research is needed at the pharmacological level to study the diseases that could be treated with the help of these wastes. Such a study based on the applications of the sugar industry wastes would allow diversification.
[43]	There is a need to examine the ways to foster the 2G biofuels supply and the local factors that need to be considered.
[44]	Technologies could be developed, and their economic feasibility should be assessed to make ethanol fuel more cost-competitive.
[45]	Studies should focus on analyzing whether the suggested alternative routes for the production of ethanol work in large-scale studies or not and further talk about how the adoption of such technologies should be done by training the people involved in these processes.

3. RESEARCH METHODOLOGY

The study is an exploratory study carried out in 6 phases:

Phase 1: Comprehensive literature review on circular economy and sugar industrial ecology

Phase 2: Understanding the circular economy in the sugar industry

Phase 3: (Quantitative analysis): Impact of inputs on sugar and molasses production

Phase 4: (Qualitative study): Important antecedents through focused group discussion

Phase 5: The circular economy in the selected sugar industry is tabulated based on the machinery and plants

Phase 6: Thematic analysis and antecedents for circular economy for the sugar industry

India is well known for its sugar production and consumption. Sugar traces its origin to the 4th century. However, the advent of the sugar industry started with the establishment of a few vacuum pans in mid-1930 in Uttar Pradesh and Bihar states of India. The first sugar plant was set up at Asaka in Orissa state, India in 1824 by the Late James Fedrick Vivian Minrich. However, it stopped in 1940, and then after a few timespans, the first sugar pan processor was set up in Saran in Bihar. The first cooperative sugar factory was started at Loni in Maharashtra, India by Padmashree Vithalrao Vikhe Patil. Indian institute of sugar technology has been built in Kanpur to improve the efficiency of sugar industries and sustain the city. The waste produced by the sugar industry is always a concern [46]. It has been found today that Maharashtra contributes to one-third of the total sugar production in the country [2]. The Government of India has Fair Remunerative Prices (FRP) for the farmers who bring sugarcane to the factories [47] ensuring a fair price for the farmers.

3.1 Scope of the study

To understand the circular economy, the sugar industry has the potential as the industry produces a lot of byproducts that are reused and recycled. Therefore, the sugar industry has been selected for the study. Maharashtra, being the hub of sugar factories in India, was selected. The research has been conducted in the sugar belt of a developing country, India, in view of exploring the process of sugar industrial ecology and its importance in developing a sustainable city. Maharashtra is one of the sugar belts in India that contributes to one-third of the sugar produced. In addition, the area under sugarcane for Maharashtra has grown substantially from 0.58 (13.13 percent) million hectares in 2001-02 to 1.24 million hectares (24.28 percent) in 2021-22 under cultivation of sugar [48]. Therefore, the present study suggests it is important to study Maharashtra, where the western part of the state accounts for a substantial number of sugar industries. Therefore, the sugar industrial network has been studied in one hundred and fifty-three sugar factories. The study has explored practices in the factories and their contribution to the sustainability of the city. The paper has also come out with a comparative study of the practices going on in the sugar factory in the past and how the practices have changed into sustainable practices at present.

3.2 Data collection

The data collection is divided into three phases. In the first phase of data collection, the byproduct process flow has been taken from the top 8 sugar factories to build structural input-output analysis. In the second phase of data collection, secondary data has been collected on all the sugar factories in Maharashtra. In the third phase, to further understand the circular economy of sugar industrial ecology, a focused group discussion was carried out. Further, eight officials have been selected from the top 8 sugar factories in Maharashtra for qualitative study. Focus group discussions have been done with the officials to understand the structural analysis of the sugar industrial ecosystem.

3.3 Data analysis

Data analysis has been classified into two parts. The structural analysis of the sugar factory has been presented through input-output analysis. The flow of byproducts has been visualized through structural input-output analysis. Descriptive statistics of sugar factories have been tabulated further. Data has been checked for normality. Further, the impact of indicators like crushing capacity (tonne/day), cane crushed (lakh MT), sugar recovery (%), molasses produced (MT), and sugarcane rate/ton on the amount of sugar produced has been tested using multiple regression. A thematic analysis of the focused group discussion was done to understand the themes to derive important antecedents for the circular economy. To carry out the focus group discussion (FGD), the stakeholders in strategic positions were selected from 9 top sugar factories. The questionnaire was formulated for the FGD. The insights from the FGD were further classified into themes and subthemes.

4. DATA ANALYSIS AND FINDINGS

This study discusses the findings from the sugar industries. The results are based on the inputs received from the experts selected for the focus group discussion from the sugar industry.

In Maharashtra, 304 sugar mills have been established and are classified as cooperative, private, or public limited. Among these, 133 are private, 97 are cooperatives, and 11 are public limited. Additionally, there are plans for 26 more factories to be established. The majority of factories, around 78%, are currently operational. The private sector has played a significant role in establishing sugar mills in the region (Table 4).

Table 4. Factory operational status in Maharashtra

Factory Nature	Closed	Proposed	Working	Grand Total
Cooperative	8	0	89	97
NA	23	21	19	63
Private	8	5	120	133
Public	0	0	11	11
Grand Total	**39**	**26**	**239**	**304**

Source: Compiled from Sugar Database Aniket Prakashan 2023

Table 5. Distillery (active/ inactive)

Factory Nature	No	Yes	Grand Total
Cooperative	40	57	97
Not Available (NA)	52	11	63
Private	81	52	133
Public	3	8	11
Grand Total	176	128	304

Source: Compiled from Sugar Database Aniket Prakashan 2023

The data presented in Table 5 sheds light on the number of factories in Maharashtra with active distillery. Out of all the sugar mills in the state, only 128 or less than 45% have an active distillery. Among the active mills, a large number of cooperative factories followed by an equally high number of private mills. Only 8 public limited mills have an active distillery. Upon closer inspection of the data, it is revealed that while about 58% of the cooperatives have an active distillery, only 39% of the privately owned mills have one. This shows that the private sector needs to establish more distilleries to catch up.

Table 6. Factory operational status

Factory Operational Status	No	Yes	Grand Total
Closed	38	1	39
Proposed	17	9	26
Working	121	118	239
Grand Total	176	128	304

Source: Compiled from Sugar Database Aniket Prakashan 2023

According to Table 6, there are currently 128 active distilleries in Maharashtra. Out of these, 118 operate within functional sugar mills. Additionally, 9 proposed sugar mills are expected to have an active distillery. However, it is important to note that several operational sugar mills do not have a distillery. Therefore, emphasis should be placed on building distilleries in these factories. This could provide numerous benefits, such as the production of various sustainable byproducts, ultimately leading to the creation of a circular economy.

Table 7 provides a comprehensive breakdown of the sugar mills situated across various districts of Maharashtra. Notably, Solapur boasts the highest number of sugar mills, with a total of 45, followed closely by Sangli with approximately 30. A number of other districts, such as Ahmednagar, Dharashiv, Kolhapur, Pune, and Satara also have more than 20 sugar mills. However, districts like Amravati and Sindhudurg have comparatively few sugar mills.

Table 7. Number of sugar factories in different districts of Maharashtra state in India

District	Number of Sugar Factories
Ahmednagar	28
Amravati	1
Beed	17
Bhandara	2
Buldhana	2
Chhatrapati Sambhaji Nagar	10
Dharashiv	24
Dhule	2
Hingoli	6
Jalgaon	5
Jalna	6
Kolhapur	27
Latur	13
Nagpur	3
Nanded	13
Nandurbar	4
Nashik	9
Parbhani	7
Pune	21
Sangli	30
Satara	23
Sindhudurg	1
Solapur	45
Wardha	2
Yavatmal	3
Grand Total	**304**

Source: Compiled from Sugar Database Aniket Prakashan 2023

Table 8. Average of sugar recovery (%)

Year_	Average of Sugar Recovery (%)
2018-2019	16.58
2021-2022	15.93
2019-2020	10.77
2020-2021	10.32
2022-2023	10.26

Source: Compiled from Sugar Database Aniket Prakashan 2023

Upon analyzing the average sugar recovery in Maharashtra, it becomes apparent that it has experienced a significant decline over time. Although the years spanning from 2018 to 2020 exhibited a favorable sugar recovery rate of approximately 15 to 16%, the post-Covid lockdown era witnessed a drastic decrease, with only about a 10% recovery rate. Additionally, the climatic conditions within the state of Maharashtra have undergone noticeable changes over the years, impacting the sugar recovery (Tables 8 and 9).

Table 9. Recovery rate

Sugar Season	FRP Fixed by the Government	Increase over Previous Year	Basic Recovery Rate
2018-2019	275	20	10
2019-2020	275	NA	10
2020-2021	285	10	10
2021-2022	290	5	10
2022-2023	305	15	10.25

Source: Compiled from Sugar Database Aniket Prakashan 2023

Structural Input-Output Analysis: The study has been carried out to analyze the input-output flow in the sugar factory. The structural input-output of sugarcane is coded as below.

1=Sugarcane	4=Bagasse	7=Consumption	10=Distillery/Spirit
2=Sugar Factory	5=Molasses	8=Paper	11=Farmers
3= Sugar	6=Pressmud	9=Fuel	

The flow is represented in a tabular form in Table 10.

Table 10. Structural analysis

(i, j)	1	2	3	4	5	6	7	8	9	10	11
1	0	1	0	0	0	1	0	0	0	1	0
2	1	0	0	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0
7	0	0	1	0	0	0	0	0	0	0	0
8	0	0	1	0	0	0	0	0	0	0	0
9	0	0	0	1	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0	0	0
11	0	0	0	0	1	0	0	0	0	0	0

Source: Compiled by Authors

Here i represents row and j represents column, A (i, j).
1=If there is a flow from process j to process i.
0=If there is no flow from process j to process i.

The top 9 sugar factories were selected and the structural analysis was done after getting the data from 8 official members. The 8 official members were selected based on their working experience in the sugar factory.

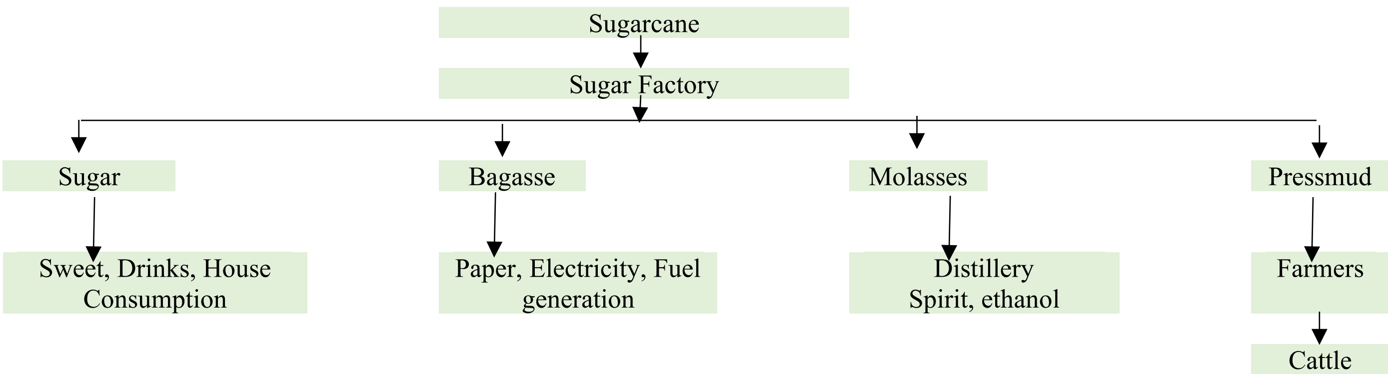


Figure 4. Structural flow of inputs
Source: Created by the Authors

Based on the tabular format of the structural analysis of sugarcane, a flow chart was prepared to analyze the structural flow of inputs for the circular economy in sugarcane.
Figure 4 represents the byproducts of sugar that are reused by the factories to develop an ecological system.

4.1 Structural analysis for circular economy in sugar industry

The Government reforms and enablers focused on protection provided for the circular economy. Sugar cooperatives have been taking care of the reuse and recycling of the byproducts produced in the sugar. The bagasse is used for generating electricity and paper making. The byproduct called molasses is used to make ethyl alcohol and biomass, butyl acetate, vinegar, biogas, and carbon dioxide used for dry ice. The remaining molasses is mixed with the cattle feed and provided to the cattle. The feed helps in increasing the milking of the cattle. The industry produces fly ash which is used to make cement. The pressmud is the byproduct that is used to make biofertilizers and generate biogas. The water used in the industry is also recycled and the treated water is used by the industry. Reuse is done through cogeneration and a distillery plant. Tables 11 and 12 show the list of sugar factories in Maharashtra which have cogeneration and distillery plant. The primary data has been collected for sugar factories in Maharashtra to explore the sugar industrial ecology.

These cogeneration plants take bagasse as inputs to generate electricity. The bagasse was thrown earlier to the environment and caused pollution. This byproduct in the sugar factory is reused in many factories to generate electricity. Pune, Ahmednagar, Solapur, Kolhapur, and Satara are a few places where the cogeneration plants have been set. This leads to economic, social, and environmental sustainability.

Table 12 lists the factories in Pune, Kolhapur, Satara, and Solhapur having distillery plant. These distillery plants use molasses as input for producing ethanol and spirit. Thousands of liters of ethanol can be produced from molasses in both private and cooperative sugar factories.

Table 11. Sugar factories in Maharashtra having cogeneration plant

S.N.	Name of the Factory	Capacity per Day (tonnes)	Capacity per Year (MT)	S.N.	Name of the Factory	Capacity per Day (tonnes)	Capacity per Year (MT)
Cooperatives							
District – Pune				35	Srigonda	30000	90
1	Bhima Sakhar	45000	95	**District – Kolhapur**			
2	Ajinkyatara	30000	90	36	Sri Chatrapati Sahu, Kolhapur	45000	135
3	Viththlarao, Solapur	30000	90	37	Vasantdada, Sangli	90000	270
4	Yashwant, Pune (Closed)	30000	90	38	Deshbhakt, Kolhapur	30000	90
5	Kisanveer, Satara	60000	180	39	Tatyasaheb, Kolhapur	90000	180
6	Raosaheb Dada Pawar, Pune	30000	90	40	Sri Datt, Kolhapur	60000	180
7	Shiromani Vasantrao Kaal, Solapur	30000	90	41	Rajarambapu, Kolhapur	75000	225
8	Yashwant Mohite, Satara	95000	285	42	Bhogwata, Kolhapur	30000	45
9	Sri Siddheshwar, Solapur	20000	135	43	Dr. D. Y. Patil, Kolhapur		
10	Neera Bhima, Pune	30000	90	44	Daulat, Kolhapur (Closed)	30000	90
11	Sri Vighnahar, Pune	30000	90	45	Kumbhi Kasari, Kolhapur	30000	90
12	Sahakar Maharshi Shankarrao, Solapur	60000	180	46	Sonheera, Sangli	30000	90
13	Someshwar, Pune	30000	90	47	Manganga, Sangli	30000	90
14	Sahyadri, Satara	45000	135	48	Appasaheb Nalawade, Kolhapur	25000	90
15	Sriram, Satara	30000	90	49	Vishwasarav Nayak, Sangali	30000	135
16	Sri Shankar, Solapur	30000	90	50	Hu. Ki Aahir, Sangali	30000	90
17	Sri Pandurang, Solapur	45000	135	51	Rena, Latur	30000	90
18	Sri Viththal, Solapur	30000	90	52	Dr. Babasaheb Ambedkar, Usmanabad	30000	60
19	Sri Makai, Solapur	30000	90	53	Bhaurao Chauhan, Nanded	30000	90
20	Malegaon, Pune	60000	190	54	Purna, Hingoli	30000	90
21	Karmayogi, Pune	30000	90	55	Sri Tuljabhavani, Usmanabad	30000	90
District – Ahmednagar				56	Terna Shetkari, Usmanabad (Closed)	30000	90
22	Sri Gyaneshwar	45000	135	57	Gangapur, Nanded	30000	90
23	Ashoka	30000	90	58	Manjar, Latur	60000	180
24	Karmveer	40000	135	59	Vikas, Latur	30000	90
25	Bhausaheb	40000	120	60	Vaidyanath, Beed	60000	180
26	Sanjeevani	75000	225	61	Manjalgaon, Beed	45000	135

27	Vasantraodada, Nashik	30000	90	62	Jai Bhavani, Beed	30000	90
28	Padmashri Viththalrao Vikhe	90000	280	63	Samarth, Jalna	30000	90
29	Sri Ganesh	30000	90	64	Madhukar, Jalgaon	30000	90
30	Sangmaner	40000	135	65	Sri Satpura, Nandurdar	75000	225
31	Dr. Bhausaheb Bapuji	45000	135	66	Siddheshwar, Aurangabad	30000	90
32	Mula	30000	90	67	Belganga, Dhule	30000	90
33	Nifad, Nashik	45000	135	68	Aambejogai, Beed	30000	90
34	K. K Wagh, Nashik	30000	90	69	Deshbhakt, Kolhapur	30000	90
			Private Sugar-Industries				
70	DahisarDistillery		45	86	Gangakhed Sugar and Energy Lt.		180
71	Godavari		180	87	Vitthal Corporation		90
72	Kolhapur Sugar Mills		180	88	Sai Krupa		90
73	Khandoba Prasanna		150	89	Karan Sugars		90
74	Lokmanagal Agro Industries		240	90	Excel Agro Tech Industries		90
75	Natural Sugar and Allied Industries		180	91	Oasis Alcohol		90
76	Payorneer Distillery Limited		180	92	Aurangabad Distillery Ltd.		135
77	Purti Power and Sugar		135	93	Vima Sagar		135
78	Shaw Valace Company		135	94	John Distillery		180
79	South Konnkan Distillery		45	95	Jubilient Lifes Sayosis		180
80	Saswad Mali Sugar		90	96	Redico N. V. Distillery		180
81	Tilaknagar Industries		90	97	Sagar Industries		300
82	Shambhu Mahadev Sugar		90	98	Vaibhav Likers		90
83	Maharashtra Shetkari		90	99	Laxmi Organic		90
84	Daund Sugar Ltd.		135	100	Gangamai and Industries		90
85	Baramati Agro Industries		90	101	Loknet Baburao Patil, Solapur		90

Source: Compiled from Sugar Database 2017

Table 12. Sugar factories in Maharashtra having distillery plant

S.N.	Name of the Factory	Yearly Capacity (KT) Litres	S.N.	Name of the Factory	Yearly Capacity (KT) Litres
	District – Pune		17	Gyaneshwar, Ahmednagar	9000
1	Ajinkyatara, Satara	3600	18	Vikhe Patil	15000
2	Malegaon, Baramati	9000	19	Sanjivani, Ahmednagar	9000
3	Vighnahar, Pune	9000		**District – Kolhapur**	
4	Sri Shankar, Solhapur	9000	20	Datt, Kolhapur	9000
5	Sahkari Maharshi	22000	21	Tatyasaheb, Kolhapur	9000
6	Viththalrao, Madha	9000	22	Vassantdada, Sangli	9000
7	Yashwant Rao, Satara	9000	23	Rajarambapu, Sangli	9000
8	Sri Pandurang, Solhapur	9000		**District – Nanded**	
9	Sri Someshwar, Pune	9000	24	Manjara, Latur	6000
10	Kisanbor, Satara	9000	25	Vikas, Latur	6000
11	Raosaheb Dada, Pune	9000	26	Rena, Latur	9000
12	Bhima, Patas	9000	27	Dr. Babasaheb Ambedkar, Usmanabad	9000
13	Sahkari Shiromani, Solhapur	9000	28	Purna, Hingoli	6000
14	Karmayogi , Pune	9000	29	Bhaurao, Nanded	9000
	District – Ahmednagar			**District – Aurangabad**	
15	Ashok, Srirampur	6000	30	Vaidyanath, Beed	15000
16	B. B Tanpure, Rahuri	9000	31	Manjalgaon, Beed	9000
			Private		
32	Gangamai, Sillod	9000	40	Renuka, Raogad	15000
33	Harneshwar Agro Industries, Valchandnagar	9000	41	Natural Sugar, Latur	9000
34	Laxmi Organise, Mahad	15000	42	Lokmangal Agro Industries, Solhapur	9000
35	Purti Sakha, Nagpur	26000	43	Baramati Agro Ltd	9000
36	RajLaxmi, Latur	15000	44	Daundh Sugar	9000
37	Vaibhav Liquors, Vashim	9000	45	Saisugar, Srigonda	15000
38	Godavari, Mumbai	25500	46	Saswad Mali Sugar	9000
39	Oasis, Karad	3600	47	Kodiba Prasanna, Satara	13500

4.2 Circular economy in sugar industry

The circular economy in the sugar industry can be possible through cogeneration plants, distillery plants, biogas, paper mills, and linkage with the cement industry. The cogeneration plant helps in the conversion of the bagasse to electricity. The electricity generated is used by the industry and also sold to the Government. The distillery plant is also found in most industries. The distillery plant helps in the conversion of molasses to ethyl alcohol. The ethyl alcohol is further used in making methylated spirit and blending of alcohol is done with petrol and diesel. The leftover molasses has also been used as cattle feed. The by-product pressmud is used for making biofertilizers. The flyash produced in the sugar industry is used in making cement industry. To further proceed with further analysis, we downloaded the data of the sugar factories from Anekant Prakashan: Search Engine of Indian sugar industry report for 2022-2023. The list of sugar factories and their data on crushing capacity, ethanol, and molasses production was used to analyze the concept of circular economy. Table 6 shows the frequency of sugar factories in Maharashtra with varying crushing capacity.

Table 13 shows that most of the factories in Maharashtra have a crushing capacity of 2001-4000 tonnes per day. Around 3 percent of the factories have a crushing capacity of more than 8000 tonnes per day. Crushing capacity is important for the circular economy as it increases the number of canes being crushed and the byproduct generated. The distribution of sugar factories can be seen in Figure 5.

Data for cane crushed, amount of sugar produced, sugar recovery, molasses produced, and crushing capacity have been used for further analysis. The molasses produced by the factories has a high standard deviation and varies among the factories. The average sugar recovery percentage is very low in the factories in Maharashtra.

The impact of crushing capacity in tonnes per day is studied on the amount of sugar produced in lakh quintal tonnes (Table 14). It is observed that factories with high crushing capacity have high sugar production (Figure 6).

Table 13. Crushing capacity per day in tonnes for sugar industry

		Frequency	Percent	Cumulative Percent
Valid	<= 2000	29	15.0	15.8
	2001 – 4000	92	47.7	66.1
	4001 – 6000	35	18.1	85.2
	6001 – 8000	21	10.9	96.7
	8001 – 10000	3	1.6	98.4
	10001 – 12000	2	1.0	99.5
	14001+	1	.5	100.0
	Total	183	94.8	
Missing		10	5.2	
Total		193	100.0	

The amount of sugar produced by the factory is positively associated with the crushing capacity of the factory. Higher sugar crushing capacity leads to high amount of sugar produced.

Figure 7 shows the plot between the sugar produced and sugar recovery. The sugar recovery in a factory is strongly associated with the sugar produced in the factory of different crushing capacity.

Table 14. Descriptive of cane crushed, sugar produced, sugar recovery, molasses produced and crushing capacity

	N	Range	Mean	Std. Error	Std. Deviation
Cane Crushed (lakh MT)	151	910	15.07	6.393	78.562
Sugar Produced (lakh quintal tonnes)	151	23	7.19	.371	4.556
Sugar Recovery (%)	153	7	10.50	.109	1.348
Molasses Produced (MT)	149	87791	29695.69	1528.631	18659.325
Crushing Capacity (tonne/day)	183	15200	3903.28	173.641	2348.975

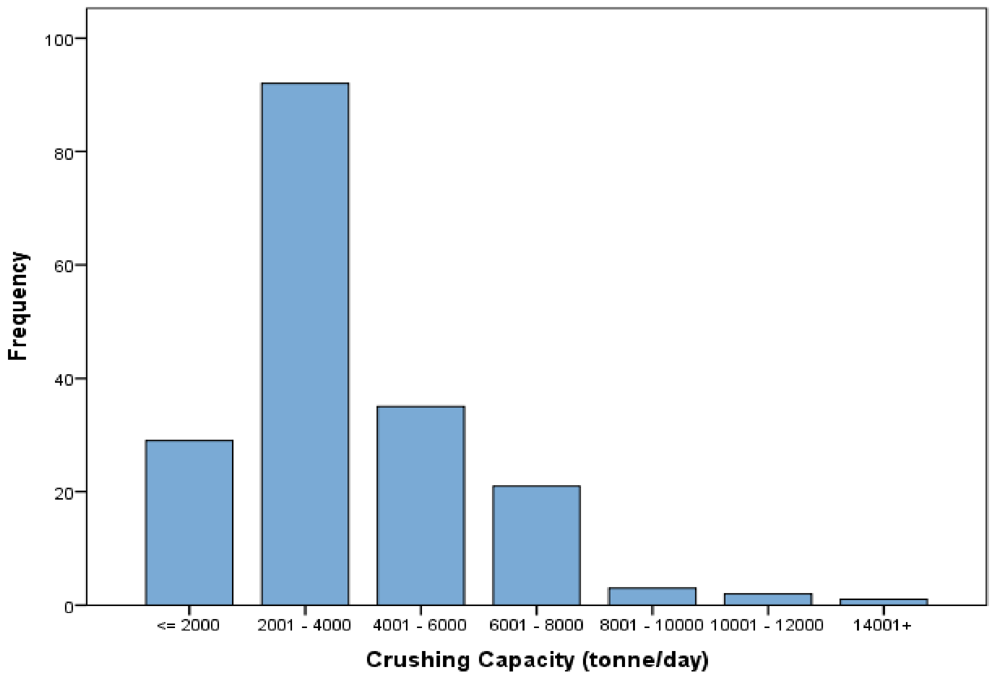


Figure 5. Sugar factories with crushing capacity

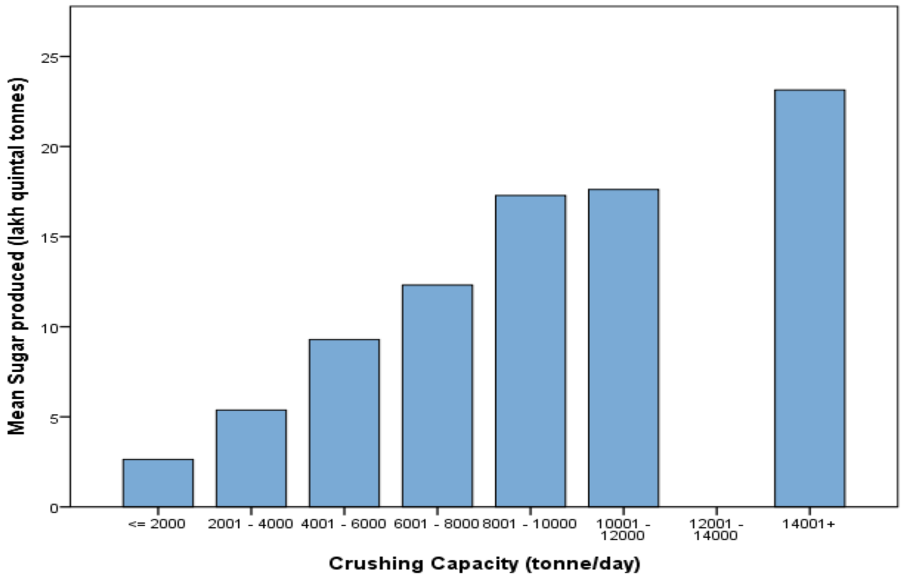


Figure 6. Sugar produced and crushing capacity

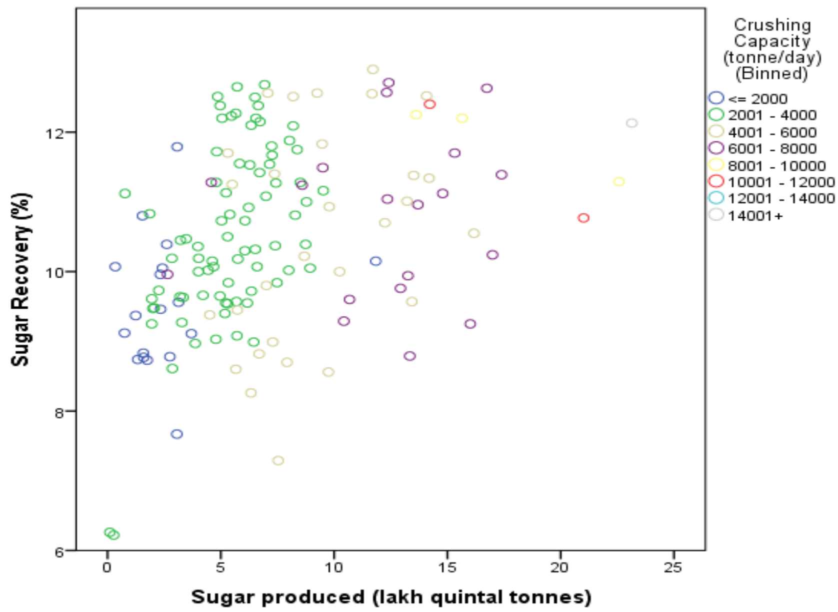


Figure 7. Sugar produced and sugar recovery

4.3 Sugar production in the sugar factories

Table 15. Descriptive of sugar production

			Statistic	Std. Error
Sugar produced (lakh quintal tonnes)	Mean		7.19	.371
	95% Confidence Interval for Mean	Lower Bound	6.46	
		Upper Bound	7.92	
	5% Trimmed Mean		6.90	
	Median		6.33	
	Variance		20.754	
	Std. Deviation		4.556	
	Range		23	
	Interquartile Range		5	
	Skewness		1.065	.197
	Kurtosis		1.165	.392

To understand the factors affecting sugar production, the data has been used for further analysis. Table 15 shows the descriptive statistics of sugar production in lakh quintal tonnes. The average production is found to be 7.19 lakh quintal tonnes for the year 2021-2022 with a standard deviation of 4.55.

4.4 Normality test

The data on sugar production has been tested for normality. The descriptive statistics on sugar produced (lakh quintal tonnes) shows that the data can be considered for parametric test as the skewness and kurtosis is in the range for normal distribution. Further to go ahead with the parametric test, data has been checked for histogram, normal Q-Q- plot, boxplot and detrended Q-Q plot as shown in Figure 8.

Data on sugar production has been further analysed to understand the causal effect relationship of sugar produced.

The data has been analysed using crushing capacity, amount of cane crushed, sugar recovery, molasses produced, and sugarcane rate as independent variables. The average crushing capacity of the factories in Maharashtra is found to be 4916 tonnes per day with an average of 7.19 lakh million tonnes of sugarcane crushed. The average molasses produced was found to be 31361 million tonnes (Table 16).

Table 17 shows the correlation between the variables. Data shows a strong positive correlation between sugar produced (lakh quintal tonnes) and crushing capacity, cane crushed, sugar recovery, and molasses produced. The sugar produced had a weak association with the sugarcane rate.

Table 16. Descriptive statistics of variables

Descriptive Statistics			
	Mean	**Std. Deviation**	**N**
Sugar Produced (lakh quintal tonnes)	7.91	4.644	24
Crushing Capacity (tonne/day)	4916.67	3463.056	24
Cane Crushed (lakh MT)	7.19	3.969	24
Sugar Recovery (%)	11.24	1.218	24
Molasses Produced (MT)	31361.17	18253.971	24
Sugarcane Rate/ton	2648.44	358.055	24

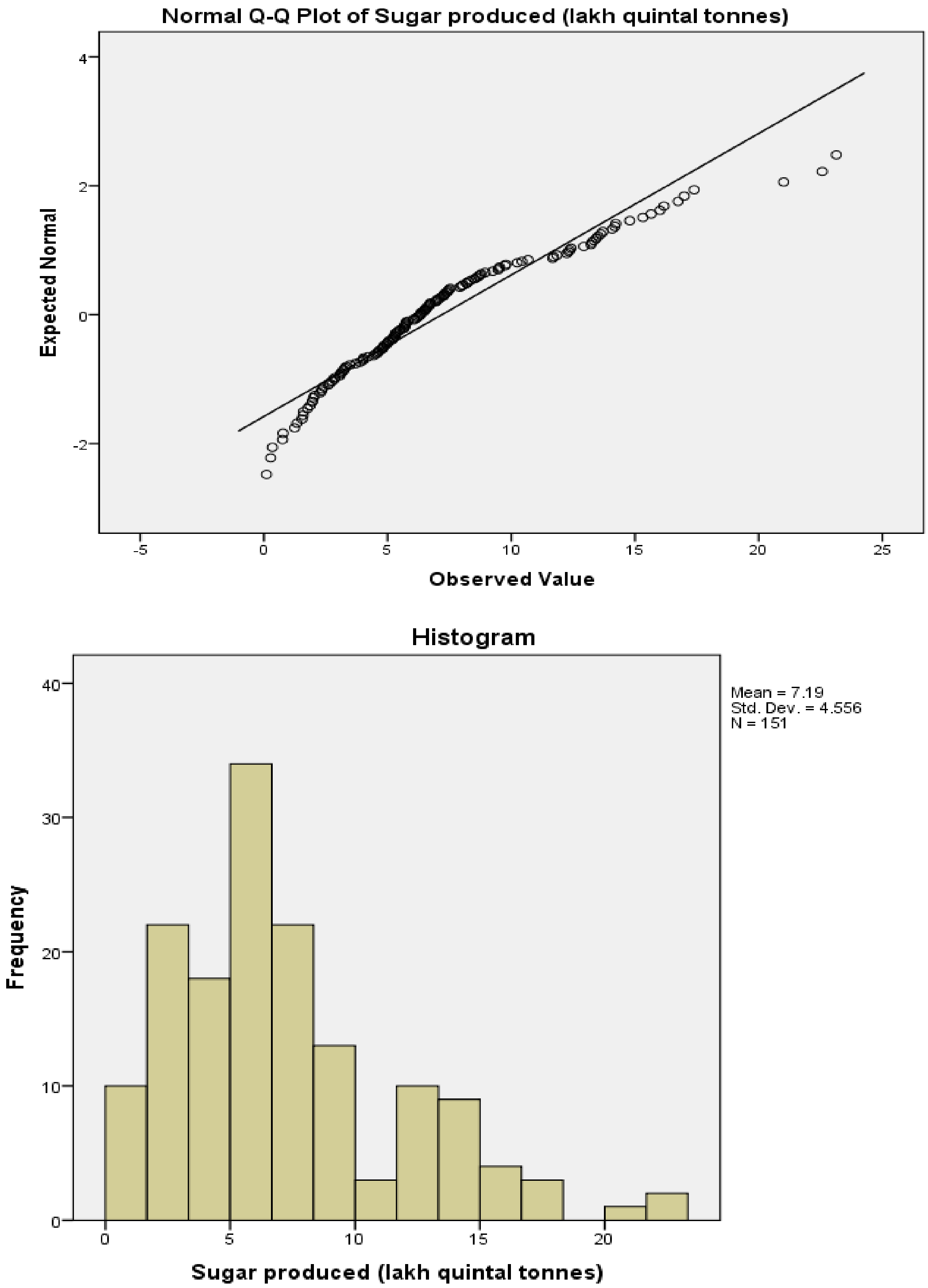


Figure 8. Normality test for parametric tests

Table 17. Correlation matrix of the variables

		Sugar Produced (lakh quintal tonnes)	Crushing Capacity (tonne/day)	Cane Crushed (lakh MT)	Sugar Recovery (%)	Molasses Produced (MT)	Sugarcane Rate/ton
Pearson Correlation	Sugar produced (lakh quintal tonnes)	1.000					
	Crushing Capacity (tonne/day)	.922	1.000				
	Cane Crushed (lakh MT)	.979	.914	1.000			
	Sugar Recovery (%)	.318	.251	.178	1.000		
	Molasses Produced (MT)	.846	.731	.895	.102	1.000	
	Sugarcane Rate/ton	.381	.283	.271	.899	.132	1.000

Table 18 shows the results of the regression summary. ANOVA table shows that the model is fit with a coefficient of determination of 0.9. 90 percent of the variation in the amount of sugar produced is dependent upon the factors selected as an independent variable.

Table 18. Regression coefficients

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.
(Constant)	-6.572	1.413		-4.652	.000
Crushing Capacity (tonne/day)	-2.167E-5	.000	-.016	-.167	.869
Cane Crushed (lakh MT)	1.304	.184	1.114	7.096	.000
Sugar Recovery (%)	.899	.311	.236	2.890	.010
Molasses Produced (MT)	-3.791E-5	.000	-.149	-1.687	.109
Sugarcane Rate /ton	-.001	.001	-.108	-1.282	.216

The results show that the sugar produced were dependent upon the cane crushed and sugar recovery percent (Figure 9). Based on the significance level lower than 0.05 the alternate hypothesis is accepted.

H1: Crushing Capacity of the Factory has a significant impact on the amount of sugar produced (Rejected)

H2: Amount of Cane Crushed has a significant impact on the amount of sugar produced (Accepted)

H3: Sugar Recovery has a significant impact on the amount of sugar produced (Accepted)

H4: Amount of molasses produced has a significant impact on the amount of sugar produced (Rejected)

H5: Sugarcane rate per tonne has a significant impact on the amount of sugar produced (Rejected)

Sugar Produced= -6.572+1.304 Cane Crushed+0.89 sugar recovery.

The amount of Molasses produced in the sugar industry was used to understand the impact of the Production Capacity Ethanol, Sugarcane Rate/ton, Crushing Capacity (tonne/day), Cane Crushed (lakh MT), and Sugar Recovery (%) on molasses produced. It was found that the model was not relati significant and the molasses produced did not have a on with the production capacity, sugarcane rate, and crushing capacity (Table 19).

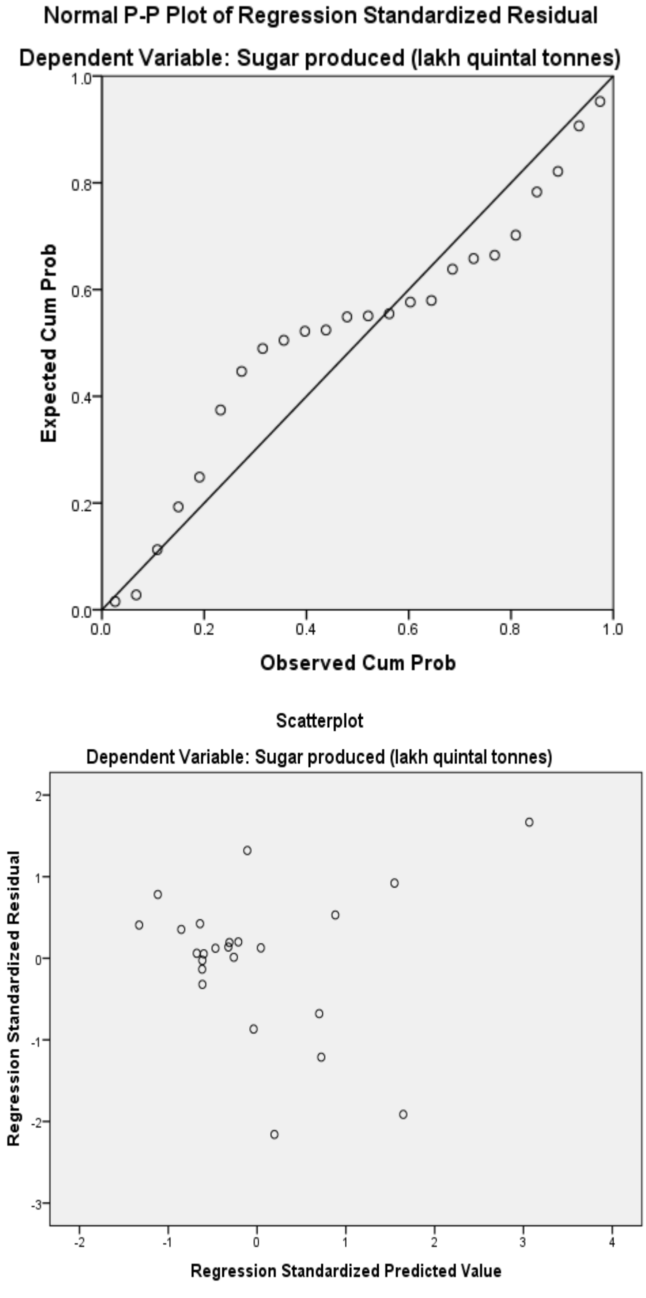
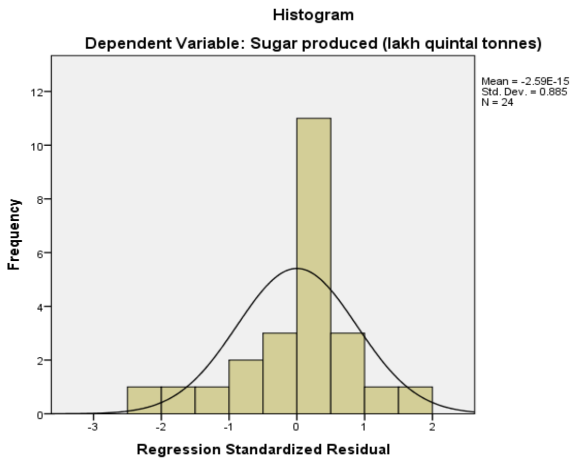


Figure 9. Normal P-P plot and scatter plot

Table 19. Residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.79	22.03	7.91	4.606	24
Residual	-1.436	1.109	.000	.588	24
Std. Predicted Value	-1.329	3.066	.000	1.000	24
Std. Residual	-2.160	1.667	.000	.885	24



4.5 Antecedents for circular economy in the sugar industry

The circular economy in the sugar industry can be possible by using machines like cogeneration plants, distillery plants, biogas, and linkage with the cement industry. The cogeneration plant helps convert the bagasse which is one of the byproducts of electricity. The electricity generated is used by the industry and also sold to the Government. The distillery plant helps convert molasses to ethyl alcohol. Ethyl alcohol is further used in methylated spirits, and the alcohol is blended with petrol and diesel. However, the circular economy in the sugar industry is influenced by antecedents that need to be explored. To further understand the circular economy of sugar industrial ecology, we did a thematic analysis of the focused group discussion. The questions specific to the themes were asked, and the responses were recorded, as shown in Table 13. The observations from the experts are discussed. After conducting the focus group discussion, the study derived important antecedents, as shown below.

4.6 Working in the sugar industry

The sugar industry has scope for reusing and recycling the byproducts, if not treated, can add to the waste. The sector is focusing on the circular economy. One of the managing directors of a sugar industry mentioned, "*The sugar Industry can generate revenue if the byproducts are efficiently utilized. The industry needs to have a byproduct plant so that waste generation can be minimized. The industry needs to focus on the utilization of byproducts. Many industries have been focusing on different byproduct plants. The sector has built biogas plants for minimizing the waste*." The industry should be more focused on byproducts than sugar. The reuse and recycling of the byproducts are influenced by the crushing capacity of the factory and the amount of sugar produced in the factory. Working in the sugar industry influences the circular economy in the sugar industry.

4.7 Adequacy of infrastructure

The circular economy needs an adequate infrastructure to set up the sugar and byproduct plants. The officer mentioned that "*The sector needs cogeneration and distillery plant. The machines and plants require space and manpower. Therefore, the sugar industry is set up in rural areas with a good infrastructure.*" Infrastructure is an important element of the circular economy in the sugar sector. Setting up paper mills, biofertilizers, distillery plants, and cogeneration plant require infrastructure. These plants need sufficient space for the reuse and recycling of the byproducts. The crushing capacity of the sugar factory requires sufficient space for the setup of the process.

4.8 Byplants

The sugar industry needs different byplants for recycling the byproducts. The cogeneration plant helps in generating electricity, the distillery plant helps in producing ethyl alcohol, and the biogas plant helps in utilizing the wastes produced in the sugar industry. One of the managers in the sugar industry said "*The industry has managed to produce electricity from the bagasse using cogen plant, ethyl alcohol from molasses using distillery plant, and biogas plant for recycling the wastes. Apart from this the industry also focused on producing cement from the flyash produced and biofertilizers through pressmud produced during the process.*" The byplants are an important element in the circular economy of the sugar industry.

4.9 Finance

Financial capital is very essential for a circular economy in the sugar industry. One of the officials mentioned in the interview that *"The setup of industry and byplants requires a huge investment. The banks are providing loans for the same but managing the investment, in the beginning, is a challenging issue"*. Sugar factories are provided with loan facilities to set up the plants and byplants. The sugar industry requires a good investment.

4.10 Human personnel

The sugar industry has a governance structure with permanent employees, temporary employees, and contract workers or seasonal workers. Personnel management in the sugar industry is essential for building technical and operational skills. The manager is one of the industries mentioned that "The sugar industry runs for a period of six months depending upon the amount of sugarcane to be crushed. The process of producing sugar, packaging, byproducts, and maintenance require human personnel for proper management.

4.11 Training

The members need to be trained in technical and operational skills from time to time. The capacity building of the members of the industry is essential for the circular economy. The machines and byplants require technical skills for handling. The industry is focusing on overall capacity building to attain a circular economy. Creation of awareness and knowledge about the byproducts is very much required for circular economy in sugar industry.

4.12 Network

There are industries that cannot set up all the machinery and byplants. One of the agriculture officers mentioned that "*The sugar industry which is weak in terms of financial capital to set up the byplant, can build symbiotic relation with the nearby industries. For example, the sugar has built a symbiotic relationship with the paper industry where the industry is providing bagasse for producing paper. The fly ash produced by the industry is provided to the cement industry for producing cement. There are industries who collaborate with the nearby sugar industry for recycling of bagasse and molasses.*" The sugar industry requires collaboration and network building for the circular economy.

4.13 Thematic analysis of circular economy in the sugar industry

The qualitative data have been further used to classify the themes and sub-themes for the circular economy of the sugar industry as shown in Table 20.

The secondary data collected through the sugar database comprised both private and cooperative sugar. It has been observed that most of the factories had cogeneration plants and distillery plants. The sugar factories are well versed to adopt a circular economy through waste management practices. Based on the thematic analysis and qualitative study, the study proposed a conceptual model for the antecedents for circular economy in sugar industrial ecology as shown in Figure 10.

Figure 10. Antecedents of circular economy in the sugar industry

Source: Created by Author

Table 20. Thematic analysis of circular economy in the sugar industry

Theme	Sub-Theme	Observations
Background	Working	Sugar industry is a growing industry since the past was known for sugar. The sector was well known for pollution and resource waste in past. The sugar industry mostly relies on contractual seasonal employees when the sugarcane is harvested.
Physical Capital	Adequacy of infrastructure	Sugar industry is located in the rural villages wherein the sugarcane can be easily brought from the farmers. The industry needs a good infrastructure for machines, plants, etc.
	By plants	With time the sugar industry has focused on 3Rs. The byplants are essential for recycling of the byproducts in the sugar industry. The industry has been focusing on the cogeneration plant and distillery plant for better waste management in the sugar industry.
	Finance	Sugar industry requires huge investment to set up the machinery. The plants for recycling the byproducts also require investments. With an initial investment, sugar industry can generate revenue from the byproducts and help in sustaining the city.
Human Capital	Number of workers	Sugar industry requires a number of permanent, contractual, and seasonal workers. Sugar is a seasonal crop therefore it works only for six months. The remaining months are invested in the maintenance of the machinery. The timing and working hours of the workers are very important as the factory remains working for 24 hours.
Technical Skills	Training	The workers are given training for understanding the usage of the byproducts. The workers are well trained in the functions of the machinery. The workers are well aware of the technical skills to run the machinery.
Industrial Ecology	Network	The sugar industry cannot afford the technology and machinery for waste management. It is therefore essential for the firms to build a network or associate with nearby industries for the recycling of the by-products. The symbiotic association of the industries can help in encouraging the reuse and recycling of the byproducts.

Source: Compiled by the Author

5. DISCUSSION

The study has followed quantitative and qualitative approach to understand the linkage between the amount of sugar produced and the circular economy. A study on the sugar manufacturing process was done to reveal that the industry produces solid wastes like sugarcane trash, bagasse, bagasse fly ash, and press mud. It has been pointed out that these wastes can be transformed into value added products like fuels and chemicals, charcoal powder, pesticides, adsorbents, wax, and additives in the cement and concrete industries [49]. The solid waste produced includes sugarcane leaves obtained after crop harvest, which are burnt triggering air pollution [37]. Better utilization in power generation, meeting energy demands to ethanol and as biochar for cooking were identified by Wilting and Ros [35]. The quantitative result shows that the sugar factories produce sugar which is dependent upon the crushing capacity and sugar recovery percentage in the factory. Bagasse is another sugarcane waste residue obtained from the industry. Ungureanu et al. [50] revealed the applications of sugarcane bagasse in valorisation of fuels, in producing biomass, converting to bioenergy, obtaining biohydrogen, biochar and many more. The significance of bagasse in nanotechnology, textile industry and pulp manufacturing has also been rising. Similarly, Shen et al. [51] found out the effectiveness of bagasse in the ethanol production, after its pretreatment process. It was shown that the pretreatment process has a potential to produce ethanol which is environmentally sustainable, and can compete with conventional fuels. When bagasse is burnt it produces bagasse fly ash. The valorisation of bagasse fly ash includes its use as an adsorbent of dyes, metals, and chemicals, as a material to be used in the construction industries and for the treatment of pesticides and insecticides which have adverse impacts on human health. It was identified that the physical and chemical properties of bagasse fly ash such as its porous nature and other versatile properties makes it an environmentally and economically viable solution [52]. Repeated crystallization of sugarcane generates molasses [53]. It is a liquid feed containing 43% of sugar. Apart from sugar, it contains sucrose, fructose, glucose, minerals, moisture and vitamins. Traditional uses of molasses are its application in ethanol production, alcohol production, as a sweetener, for digestion, to cure anaemia, and as a fertilizer, among others. It can be used to produce value-added products like fructose, butanol, lactic and gluconic acid. It has therapeutic benefits like protecting healthy tissues, providing defense against bacteria, and immunity. Its chemical properties make it potentially useful in providing health benefits. It is identified as an economically viable waste product which can be utilized in the sustainable production of biofuels replacing the already existing fossil fuels, transitioning to a more environmentally friendly and cost-effective technology. Its chemical properties make it potentially useful in providing health benefits. Schmid et al. [54] found that due to high production cost of poly(3-hydroxybutyrate) it is very difficult to commercialize the polymer, however the use of sugar beet molasses in the desugarsied form shows a potential to produce the same at a lower cost allowing P(3HB) to be used in a variety of applications, one being its use in the medical field. The P(3HB) had an increase in its concentration by a factor of 3.5 when desugarised sugar beet molasses were used, instead of mineral salt medium. Zhang et al. [55] pointed out that the molasses can be used to obtain carbohydrates, industrial enzymes, organic acids, and a variety of other products. It has been identified that the use of molasses has increased over the past few years in the field of energy, food and pharmaceutical industry, where it provides a low cost residue. Vinasse is another important waste having high organic content chemical and biological oxygen demand, which lead to harsh environmental impacts. In order to stop these wastes from negatively impacting sustainability, alternative use of these byproducts have been studied [42]. Wastes like B and C type molasses and vinasse can be used as antioxidants which would increase their therapeutic value. A study was also done identifying that poor management of wastewater and limited technologies to remove all the pollutants at a time leads to increase in chloride, sulphate, nitrate, calcium, and magnesium, increasing potential threats of pollutants. Wastewaters are discharged into the water bodies causing water pollution. It was reported that about 1 meter cube of wastewater is generated from every ton of cane crushed. The improper management of the industrial wastewater is a result of the limited technologies, and the complex nature of the wastes generated from sugar industries like COD and BOD, which endanger aquatic life as well. It is emphasized that wastewater management through common practices like ferti-irrigation, bio compost, and concentration by evaporation need to be adopted. The study points at the trend towards development of biological treatment systems which are viable and cost effective. High-rate anaerobic digesters, anaerobic filter and adsorption treatment technology are some emerging technologies which can play an important role in water conservation and recovery [56].

The findings show that the amount of sugar produced in a factory is dependent upon the crushing capacity and sugar recovery rate. The crushing capacity of the factory influences the amount of sugarcane crushed. The amount of sugarcane crushed leads to high amount of sugar produced. The data was run to understand the factors that influence the production of molasses. However, the results did not show a significant result for the molasses produced and the factors studied. This may be due to the working pattern and byplants of the factories. Therefore, further the study performed a qualitative study to triangulate the findings from the quantitative data. The focus group discussion resulted in exploring the antecedents for circular economy in sugar industry. The antecedents like training and byplants are important for circular economy in the industry [45]. The study adds to a unique contribution in generating revenue through circular economy. Making cement, bricks, paver blocks, activated binder, and other building materials from secondary by-products from the sugar industry lowers the carbon impact of the construction industry while improving the quality of the finished goods. From the perspective of the sugar industry, such a plan eliminates disposal problems and produces additional revenue. Although there are distinct research studies looking at the use of byproducts from the sugar industry, few studies consider these options for valorisation all at once to reduce waste and create an efficient material flow chain. By identifying different material and energy recovery routes from published literature, this study links the materials and processes to create a continuous material supply chain with the least amount of waste. Creating a symbiotic structure results in minimum wastes [57]. We noticed a dearth of financial support for the adoption of CE. Significant expenses linked to the businesses examined demonstrated that they rely on technology investments to advance their ongoing CE projects, such as those involving bioenergy, biogas, and solar. The present study has analyzed the secondary data for sugar factories in Maharashtra followed by a qualitative survey to understand the antecedents for circular economy. It was observed that the circular economy in sugar industry depends on other factors which are yet to be explored. The qualitative findings helped in tabulation of the themes essential for the circular economy in sugar industry. The study also signifies the procurement of sugarcane and other byproducts for sugar, ethanol, electricity generation.

6. IMPLICATIONS OF THE STUDY

The strength of sugar cooperatives cannot be ignored despite several problems the sector is facing in the present competitive environment. The industry has a scope of circular economy, and therefore micro-level planning for identifying the current and future developmental needs of the sugar sector is essential. The study has documented the importance of industrial ecology which will benefit the practitioners and academicians in linking the circular economy with the sugar industry.

6.1 Theoretical implications

The study has added to the literature on the circular economy adopted by the sugar industry. The study discusses the different reuse and recycling of the byproducts by the industry. The usage of the byproducts is well known by society but the linkage with the circular economy is a unique contribution of the present study. Secondly, the study has undergone a qualitative methodology to understand the insights from the officials working in the sugar industry. The insights have been further used to build a structural analysis of the input-output of the sugar industry sector. Thirdly, the study has performed a thematic analysis to understand the views of the experts on the themes and subthemes for a circular economy. The insights on sub-themes can further help in linking the factors for circular economy in the sugar industry.

6.2 Managerial implications

The study has also resulted in managerial implications. The study can be beneficial for the practitioners who are yet to link waste management with the circular economy. Secondly, the study paves a way for practitioners to understand the importance of a circular economy for developing sustainability. Many practitioners are unaware of the circular economy. Thirdly, the study can result in further understanding of the different antecedents for circular economy in the sugar industry. The sub-themes of the qualitative study highlight the measures through which the practitioners can attain a circular economy. The study will help the stakeholders of the sugar factory in understanding the utilization of byproducts in the form of paper, electricity, ethanol, bricks, pressmud, fertilizer, dryice etc. The themes from the FGD will help to strategize the measures for circular economy.

7. CONCLUSIONS

Sugar industrial ecology has led to circular economy through the antecedents discussed in the findings. Sugar factories have built cogen plant and distillery to reuse the byproducts from sugar production. The secondary data analysis shows that the amount of sugar produced in a factory is dependent upon the crushing capacity of the factory and the sugar recovery rate. The sugar recovery rate is the conversion rates for sugarcane to juice, ethanol and sugar. The structural input output analysis carried out in the study shows the flow of byproducts into revenue generating produces. The results from focus group discussion displays the antecedents for circular economy in sugar industry. The reuse, reduce and recycle of the byproducts are essential in sugar factory but it is important to understand the antecedents that lead to circular economy. Capital, technology, infrastructure, knowledge, monitoring, and expertise in waste management practices act as the enablers for industries to make an industry sustainable. It has shown the availability of machinery in the form of a cogeneration plant and distillery plant in Maharashtra. The study has presented the results of focus group discussion. The qualitative results have been shown as thematic analysis. The thematic analysis and qualitative study have led to the important antecedents for circular economy in the sugar industrial ecology. The study has discussed different byproducts and usage of the sugar sector. The study adds a significant contribution to waste management. Though the study findings can be useful for circular economy and waste management yet the results are limited to the findings from the sugar belt. The condition in the non-sugar industry belt and other industries need to be explored for exploring the approaches to the circular economy. There is a scope of different byproducts that need to be explored. The study paves the way for future research directions. The antecedents discovered in the study can be linked with a theory. The results from focus group discussion shows the themes emerging for building a circular economy. It is essential that the themes can be validated through primary survey conducted for the sugar factories and understanding the themes and subthemes through primary surveys. The study can also be further extended in exploring the innovative practices of the sugar factories towards circular economy.

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