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Green and Sustainable Packaging Manufacturing: a Case Study of Sugarcane Bagasse-Based Tableware in Egypt

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Abstract
Bagasse-based products contribute to solving the plastic pollution problem. This paper presents an alternative by producing bioplastic products that can be manufactured in many forms ranging across different industries such as food packaging, single use tableware, and crafts. The researchers aim to prove the alternative's market variability through conducting a feasibility study of establishing a technological manufacturing plant producing bagasse-based tableware in Egypt. Researchers performed different scenarios aiming to reach the best cost, quality, resources, and profitability of producing bagasse biodegradable tableware in Egypt as a replacement of Styrofoam and validated the base scenarios using "Powersim simulation tool". Practical impact of this researcher is to assist in promoting low-carbon economy solution in addition to producing safe bioplastic products replacing Styrofoam for food packaging and tableware fabrication.

Keywords Bagasse · Biobased plastics · Sugarcane · Feasibility · Sustainable

Introduction

The aim of this paper is to present an alternative by producing bioplastic products that can be manufactured in many forms ranging across different industries such as food packaging, single use tableware, and crafts. Specifically, the authors are interested in better using

Significance Statement Manufacture food packages and packing materials at competitive price from bagasse pulp, based on an innovative green process. This method reduces energy and water use in manufacturing by about 50%. The low cost of producing bagasse pulp, simple manufacturing process, reusing waste, and high market potential are the factors that encourage leveraging this industry in Egypt.

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sugarcane bagasse cellulose fibres in the production of tableware products. To achieve this aim, the authors have used an interdisciplinary approach combining engineering with marketing feasibility studies to test the market viability of the suggested bioplastic products. This paper is structured as follows: "Aspects of Green Material Selection" section covered the aspects of green material selection. "Literature Review" section covered the related literature review. In "Research Design and Methodology of the Lean Manufacturing Process" section, we detailed the research design and methodology of the lean manufacturing process used to achieve the research results. "Results and discussions" section presents the results, while the last section is dedicated to concluding remarks.

Aspects of Green Material Selection

The global shortages of resource and environmental pollution are intensified by urbanization and industrialization. Sustainability concept became more crucial on the back of this aggressive global trend. In the design-manufacturing process, the selection of sustainable green materials is essential, aimed at achieving product quality and reducing the impact both on the environment and the human health. However, various parameters or criteria, such as cost, physical property, availability, and environmental footprint, should be conducted in parallel when selecting the right green material for product designs [1]. It goes without saying that each material has unique characteristics, and no material can satisfy all relevant attributes. In selecting materials, engineers must consider multiple criteria, including economic, environmental, and social criteria summarized in Table 1.

The correct green material selection will achieve the movement from traditional plastic to biodegradable bagasse-based plastics. Plastic industry is now taking a new era towards biodegradable, environmentally friendly plastics due to the harmful effects of synthetic plastics. Styrofoam, so-called polystyrene (PS), is a versatile polymer, and it is primarily used in consumer goods packaging, but the fate of such items causes environmental pollution after their use because they are non-degradable. The primary concern is related to the effect of synthetic plastic debris and Styrofoam on the marine ecosystem pollution, human health, economy, and social value. Styrofoam debris is abundant on coasts leaving negative impact on the marine system beside damaging the land view, thus lowering beach value and tourism. Different Styrofoam types are broken into small fragments into the marine system—especially the so-called high-density Styrofoam buoys, with a density of 0.02 g/cm^{-3} which is easily ingested by the marine biota and lead to entanglement of marine life, chemical pollution, and degradation of the landscape [2]. Various studies reported serious microplastic pollution caused by Styrofoam buoys pieces on beaches in South Korea [2]. Cleaning up of the fragmentation and scattering pieces seems to be difficult due to lack of systematic collection, and lack of a requirement for recycling, so the collected Styrofoam is the intact one, not the fragmented with the higher danger upon the environment [2]. Besides, Styrofoam manufacturing depends on nonrenewable sources such as gas and oil, acting as a source of persistent pollution with an absolute negative effect on global warming [3]. However, there is a wide application of Styrofoam in food packaging since it keeps the food quality and freshness. Moreover, the packaging allows easy identification of the contained product, storage, and distribution convenience, but the authors cannot overlook its bad environmental impact, so the design of packaging material should not be done only based on the cost and food shelf-life and safety, as well as practicality, but also on environmental sustainability [4].

Table 1 Aspects of green material selection [1]

Goal level	Cluster level	Criterion level	Definitions	Attributes
Green material selection	Economic (E_1)	Initial cost (C_1)	The cost which is to be spent the material manufacturing	Cost
		Maintenance cost (C_2)	The cost which is to be spent for the maintenance in its effective lifetime	Cost
		Disposal cost (C_3)	The cost which is to be spent for end-of-life disposal of the material	Cost
		Tax Contribution (C_4)	Tax involved and contributed by the material	Benefit
	Environment (E_2)	Energy saving (C_5)	Net energy saved by the material	Benefit
		Potential for recycling and reuse (C_6)	Recycling and reuse capability of the material	Benefit
		Raw material extraction (C_7)	Limited extraction of the raw material for the manufacturing of the final material	Benefit
		Usage of water (C_8)	Usage of water involved in the life cycle of the material	Cost
		CO_2 emissions (C_9)	CO_2 emission of the material in its useful lifetime	Cost
	Physical property (E_3)	Density (C_{10})	The estimated measure of content per functional and lexical units in total	Benefit
		Rigidity (C_{11})	The capacity to resist a hard object pressed into its surface of local materials	Cost
		Tensile strength (C_{12})	The ability to resist permanent deformation and destruction	Benefit
		Elongation at break (C_{13})	The ratio of the original length and the displacement value when pull-off	Benefit
		Tensile modulus (C_{14})	Elastic when stretched for materials	Cost

The use of Styrofoam for food packaging should step back because of the harmful effect it has on human health and environment from different aspects as shown in Table 2. It causes respiratory diseases and produces carcinogens plus the radiations depleting the ozone layer which reflects upon human health too. Not only this, but it also depletes the ecosystem quality, and triggers aquatic eco-toxicity by causing aquatic acidification, aquatic eutrophication, and land occupation. In addition, the climate change because of global warming is due to the reliance on nonrenewable sources and mineral extraction in the Styrofoam manufacturing process [4]. Furthermore, the recycling process of Styrofoam is complicated and has a very high energy consumption. Additionally, it loses its foamy character despite the recycled product can be re-gassed but with higher expenses making the final recycled product more expensive than the original one [5].

Literature Review

Several countries started banning the use of synthetic plastic such as the UK, China, Montreal, Australia, Canada, Hamburg, France, Morocco, and New York [6]. The eventual fate of nonrenewable resources increases their demand for sustainable products and expands the chance for bioplastics to gain higher market share. Currently, packaging remains the leading field for bioplastics with almost 65% (1.2 million tons) of the total bioplastics market in 2018. Published statistics in 2017 showed that 2.05 million tons of bioplastic is being produced globally; this market is expected to grow by 20% within 5 years and reach approximately 2.44 million tons in 2022 since there is a stable increase in bioplastic production and consumption in different countries all over the world [7].

Numerous raw materials are being used for bioplastic production like polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (PBS), and starch blends. However, they are considered expensive sources in Egypt either because of their high costs or unavailability. Oxo-degradable plastic is a cheaper option but its fragments quickly degrade into smaller pieces left in the environment indefinitely, which opposes the idea of bioplastic and its positive impact on the environment [8]. On the other hand, sugarcane waste (bagasse) is a promising raw material for producing biodegradable plastics. There are 130 countries that produce 77% of sugarcane worldwide; 191 countries are registered as sugar producers [9]. Bagasse waste was burned in fields; thus, a lot of pollution was caused due to lack of awareness of environmental threats.

Bagasse is a highly competitive alternative to be considered in bioplastics production rather than burning. Bagasse is an organic sugarcane fibre product that remains after the juice is removed from the sugarcane [10]. The main constituents of these fibres are cellulose, hemi-cellulose, lignin, and pectin. Bagasse has a variety of unique physical properties and can be chemically modified. Besides, extraction costs, chemical changes and other bagasse pre-treatments are cheap. The fibres in bagasse strengthen the mechanical

Table 2 The negative feedback of Styrofoam use on the environment [4]

Resources	Oil, crude, in ground, Gas natural in ground
Climate change	Carbon dioxide, fossil
Human health	Nitrogen oxides, sulphur dioxide, hydrocarbons, aromatic, Particulates
Ecosystem quality	Zinc, nitrogen oxides, aluminium

properties of the final tableware, including tensile strength, flexure strength, flexure modulus, hardness, and impact strength [11]. The mechanical properties of bagasse are enhanced when treated with boiling water compared to using it in its dried form without wetting and the reason behind this is believed to be the ability of water in decreasing the gummy nature of bagasse and in removing any attached particles on the surface. Another treatment procedure used is “silane treatment”; it was proved to increase the fibre surface area making it rough with striations and gave better composite properties regarding fibre adhesion, and the water absorption also decreased after treatment promoting adhesion. This reduces the dependency of the products’ quality on the cultivation type of bagasse or its origin allowing the use of bagasse from different sources into the same batch production after milling and mixing [12].

Bagasse can be used in a wide variety of applications, e.g., packaging, furniture, and electronic display materials; it has short fibres which produce tissue, boxes, and high printing quality papers and improves paper porosity. The high fibre content is a good source for animal bedding and animal feed like rabbits [13]; after treatment, it can be used as a fertilizer for indoor plants or even new agricultural lands as it contains high percent of minerals and nutrients [13]. It is also used in manufacturing of sustainable acoustic absorbers [14], and treatment of underground water. It is considered a useful tool in “building and construction” as it is involved in glass, ceramic materials, boards, green building bricks, and flooring tiles [11, 13].

The economic importance of bagasse in Egypt lies in power generation. The sugarcane industry is the only industry that is characterized by being dependent on the self-production of the energy required for it, as bagasse left over from squeezing the cane is used as fuel for the steam boilers to generate the energy needed to manage machinery and industrial processes. The production of the sugar represents about 1.6 million tons of dry bagasse, the amount of which is equivalent according to the heat equivalent of about 530 thousand tons of diesel with a value of about 70 million Egyptian pounds. Diesel, in addition to the expenses of using diesel as an alternative to bagasse, as the value of the bagasse produced from an acre of reeds is about 386 pounds/acre. The increase in the thermal content of bagasse is used to generate steam by creating a bagasse dryer in order to dry the wet bagasse from 52 to 45% humidity, thus achieving a surplus of bagasse of 19% which is also directed to other economic uses. The goal of drying bagasse is to increase its calorific value, which is inversely proportional to the moisture content, as well as the decrease in humidity, which leads to a decrease in the weight of the combustion gases, which reduces the heat loss.

Additionally, the manufacturing process of bagasse containers will be based on lean manufacturing concepts to achieve maximum sustainability. The goal of lean manufacturing of bagasse is to minimize costs and increase production through waste and non-value-added activities’ elimination [15, 16]. Some empirical studies concluded that lean and green production systems can co-exist [17–20]. Dornfeld et al. in 2013 mentioned that the integrated manufacturing process should minimize negative impact on environment by saving energy and natural resources and reusing agricultural wastes [21].

Some of the key obstacles impacting the future competitiveness of many manufacturing SMEs are enhancing environmental sustainability and preserving operating quality while achieving cost-effectiveness production process [22]. The problem becomes severe when such businesses use batch manufacturing systems that are commonly used by many SMEs. Small amounts of product/output are processed in a batch processing method in the same phase as before moving to the next step in the manufacturing process [23]. In comparison with continuous production lines, batch manufacturing systems requires low capital investment and a large number of non-value-added activities impacting overall performance and efficiency. Some of the non-value-added activities may be viewed as "waste" [24].

Lean thinking aims to systematically reduce waste transforming any production process to a more efficient system. But this is only one side of the story increasing productivity, but what about environmental impact. Fewer businesses have acknowledged that lean and green are mutually beneficial. When lean instruments are used by these businesses to minimize lean waste, green waste is unintentionally reduced. These businesses therefore use a lean and green integrated approach based on lean and green synergies.

Research Design and Methodology of the Lean Manufacturing Process

This work introduces a technological process for using bagasse as a substitute of Styrofoam food containers with the advantage of being a biodegradable plastic. Bagasse is a promising replacement of Styrofoam in Egypt, since it solves the sustainability challenge with food, energy, and waste.

Data Bridge Market Research stated in its report published in January 2021 that biodegradable paper and plastic packaging market in MENA region will grow at CAGR of 3.1% over the forecasted years of 2021 to 2028 reaching a total amount of USD 68,696.68 thousand by 2028. Egypt's share is still limited but growing at fast rate that slightly exceeds the MENA rate; it grows to replace the traditional single use plastic tableware [25].

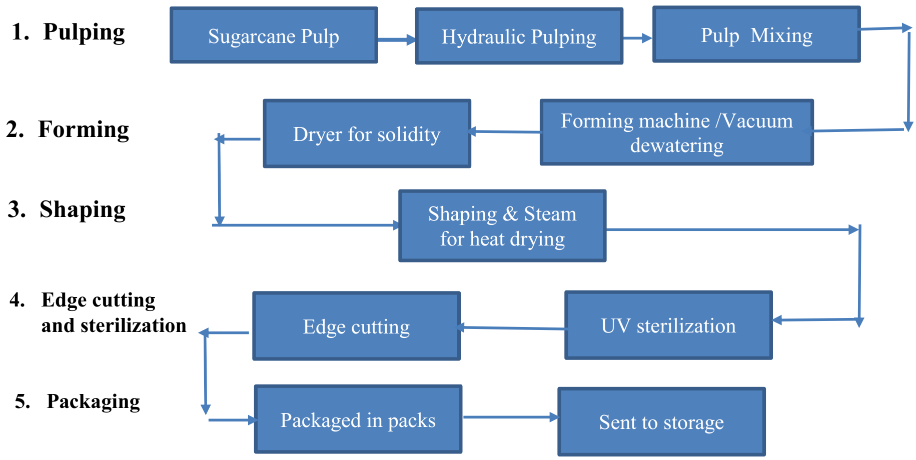
The manufacturing process introduced depends on a lean and sustainable manufacturing process. The goal of lean manufacturing is to minimize costs and increase production through waste and non-value-added activities' elimination [15, 16].

To prove the feasibility of utilizing sugarcane bagasse pulp as a replacement of Styrofoam in tableware industry in Egypt and the viability of the product understudy, the authors do the following:

1. Compared the performance of both raw materials.
2. Estimated the transportation and manufacturing costs of both raw materials.
3. Allocated the lean wastes during the manufacturing process to achieve lean manufacturing.
4. Calculated the various revenue streams within the analysis to show the value added for using bagasse.
5. Calculated different scenarios and using Powersim simulation tool to verify the results of the feasibility study; Powersim Software provides customizable solutions, and it is considered a dynamic tool for continuous decision-making in manufacturing.
6. Conducted 5 scenarios testing all possible market conditions.
7. Took the final decision and selected the best scenario and use the simulation tool verified the net gains of bagasse production calculate.
8. Selected the indicators for bagasse raw material selection that suits the manufacturing process bases on the aspects of green material selection mentioned in the introduction.

Results and Discussions

The main raw material is bagasse pulp which is obtained from sugar making plants. The process includes five key steps covering pulping, moulding and drying, sterilization and edge trimming and finally packaging. The following flowchart highlights the production process of bagasse-based tableware. The idea behind understanding the technical process allowed the authors to estimate accurately the cost and the revenues of the manufacturing process as shown in the first two sections of the results. A further step was needed after calculating the revenues and costs. The authors allocated several technical assumptions that were reflected in the different scenarios proposed to minimize the cost of production of this novel process. Finally, the technical manufacturing process was evaluated accurately using a simulation modelling to study the cost of investment and the profits generated.



A raw material comparison between Styrofoam andbagasse is performed in terms of density, price per ton, price per piece, volume and weight as illustrated in Table 3.

Cost Estimation of the Lean Manufacturing Process

The bagasse pulp is received wet in the form of sheets; it is dried using heating to protect it from spoiling during the storage period. The production process begins by immersing

Table 3 Raw material comparison

Material	Bagasse	Styrofoam
Density kg/m^3	1280	20
Price/ton EGP	85.47	1700
Volume m^3	0.00012	0.00024
Weight kg	0.1536	0.0048
Cost USD	0.013128	0.00816
Cost/piece EGP	0.20	0.13

Fig. 1 Mixing bagasse pulp

Fig. 2 Pumping system

the chopped bagasse pulp in 95% water (Fig. 1) and adding oil and water repellent for preserving the final product. One percent of both the oil-resistant agent (solid content 23.48%) and the water-resistant agent (solid content 21.76%) is added. The addition of the oil repellent avoids the spoiling of the tableware bagasse products from oily food, and the water repellent is used to add the hydrophobic property to the final fabricated tableware. The water-resistant agent and oil-resistant agent refer to a series of additives that reduce the surface tension of paper prevent leakage. The homogenous paste after passing through three mixing stations is pumped using a well-designed pumping system (Fig. 2) to the forming moulds at a temperature of 150 °C with constant pressure of 0.024 MPa at 10 min (Fig. 3) to take its final shape. The semi-finished product is transferred from the forming moulds to the drying moulds to remove moisture. The bagasse tableware products are then moved to the trimming machine (Fig. 4); each final product shape will need its own trimming machine to cut any extra edges formed during

Fig. 3 Forming

Fig. 4 Trimming machine

the production process so the final shape would be symmetrical. The cost of producing sugar is not included in the process since the waste of the sugar is the one that is used. The only cost that is accounted for is the cost of changing the sugar waste into pulp.

The authors also synchronized the wastes requirements in the new proposed biodegradable tableware production process in Table 4. The wastes are classified into lean

Table 4 Synergy between lean and green wastes in the biodegradable tableware production process in Egypt [26]

Seven wastes	Description of waste	Lean waste	Green wastes
Over production	Products sold at a reduced price because of limited demand	Storage, excess production time, scrap	Energy, space
Transportation	Unnecessary movements that waste time, effort and might harm the product	Travel, packaging scrap	Transportation, materials
Inventory	Extra storage, inefficient usage of working capital	Storage, materials	Energy, materials
Motion	Uncalculated movements affecting costs and cause injuries	Time, energy	Energy
Waiting	Unsynchronized production process	Time, energy	Energy
Defects	Re-work	Scrap, time	Garbage, material, energy
Over processing	Lack of standardization making it a workshop not a factory	Time	Energy

Table 5 Consumption and monthly costs

Description	Unit price (EGP.)	Consumption	Cost/h (EGP.)	Cost/day (8 h)	Cost/month (EGP.) (26 days)
Pulp	14,000/ton	5 ton/month			70,000
Electricity	0.55/kW	100 kW/h	55	440	11,440
Water	0.45/L	90L/h	40.5	324	8, 424
Oil and water	320/kg	0.2 kg/h			13,312
Factory rent	18,000				18,000
Labour	5000/month/worker				10,000
Total					131,176

Table 6 Estimate price of the machines for manufacturing tableware (http://www.geotegrity.com)

Machine	Quantity	Price (EGP.)
Heater	1	166,500
Crushing machine	1	40,000
Compressor	2	100,000
Forming machine	1	125,000
Pulp mixer	1	56,000
Soft pulp mixer	1	52,000
Production pulp mixer	1	52,000
Control panel for pumps	1	14,000
Loading pumps (3pcs)	1	12,000
Control valves for pluming	1	7,500
Suction pump + tank	1	30,000
Return tank	1	8,000
Moulds	3	159,000
Cutters	3	90,000
Trimming machine	1	35,000
Total		947,000

wastes and green wastes. The importance of classification of waste is to achieve the lean manufacturing process.

The cost of the lean manufacturing depends on the factors mentioned in Tables 5 and 6. It includes the raw materials used (bagasse pulp, oil, and water repellent), water and electricity consumption, the number of workers needed, the plant rental cost, and the machines used for bagasse-based tableware production. The bagasse pulp price is 14,000 EGP/ ton; 5 tons will be produced each month as a start. The price of the raw material is (5*14,000) 70,000 EGP/month. The cost of the oil and water repellent added is 320 EGP/kg. The amount used per day is 1.6 kg (0.2 kg/h. for 8 h/day). This adds up to 42 kg/month. The total cost of the oil and water repellent per month is 13,312 EGP/month. The suitable area of the factory is 180 m^2; the rental cost is 18,000 EGP monthly. Two workers are hired for 8 h/day for 26 days per month. Their salaries are 10,000 EGP/month. The total price for the machines required for running the plant is 947,000 EGP including three different forming moulds and their corresponding trimming machines. The chosen semi-automatic machines' working capacity allows the production of about 750 pieces/h.

Revenue Streams Calculation

The calculation of revenue streams is based on Table 7. This study is targeting certain segments such as food outlets and restaurants, retail chains selling to consumers, and companies with green initiative as they use tableware and packaging daily. Furthermore, the authors investigated the added value as a result of manufacturing by-products resulting from the sugar industry, which is the main product of sugarcane and sugar beet, which represents a great value and a great relative importance. The value of molasses produced from an acre of sugarcane is about 3264 EGP, and the value of the slurry produced from the filters for the sugarcane industry for 1 acre amounts to about 162 EGP, in addition to the value of the bagasse products, which are about 7270 EGP, and then, one acre of sugar cane achieves a return of about 10.7 thousand EGP of by-products, and thus, the net yield of 1 ton of sugar cane can be calculated about 209 EGP, as it is clear that the price of a ton of sugar cane increased by 105 EGP, to become about 305 EGP.

Cost estimation of Transportation of Sugarcane Bagasse Pulp

The governorates with the highest sugarcane cultivation yield in Egypt are allocated. This is followed by estimating the number of vehicles required for the monthly transportation of Bagasse pulp from one of those governorates to Cairo where the manufacturing plant will be allocated. This will entirely depend on the size of the bagasse sheets and the number of sheets required for monthly production in Cairo. The bagasse pulp will be transported from the most widely cultivating governorates for sugarcane in Egypt to the plant site in Cairo. According to the Ministry of Agriculture and Land Reclamation in Egypt, the largest area for sugarcane cultivation is Qena governorate; it occupies 57% of the total sugarcane cultivation land followed by Luxor, Aswan, Menya, and Suhag, respectively, as illustrated in Table 8.

The bagasse sheet specifications shown in Table 9 were essential in calculating the transportation fees, as the number of vehicles required will depend on the vehicle capacity, according to the size and weight of the sheets (Fig. 5). The capacity of the shipment trucks required is 2 tons/vehicle, accordingly; the transportation of the 5 bagasse pulp tons required every month for production requires three vehicles. The cost of transportation from Qena (chosen as it has the highest sugarcane production) to the plant site per vehicle will be 10,000 EGP; hence, the total monthly costs for bagasse pulp transportation will be 30,000 EGP.

Table 7 Revenue streams

Buyer	Prices & payment terms
▪ Restaurants: requiring their own designs boxes, plates and tableware matching specially designed for them ▪ Companies with green initiative: requiring boxes, plates and tableware matching their brands	Payment terms cash with no discount Price \$0.854/piece Product not standardized
▪ Retail chains selling to consumers: More standardized affordable products ▪ Food outlets: selling fast food to youth	Payment terms cash with no discount Price \$0.3–\$0.2/piece Standardized products

Table 8 Distribution of Sugarcane cultivation in Egypt [27]

Governorate	Cultivated land (feddan)	Yield (ton)
Qena	114,247	5,659,796
Luxor (Edfo)	62,190	3,085,308
Menya	38,757	1,903,162
Suhag	15,663	790,355
Aswan	80,143	3,959,385

Table 9 Sheet specification

Length	2 m
Width	1 m
Height	0.002 m
Wt. of 1 sheet	5.124 kg

Fig. 5 Bagasse pulp sheets

Feasibility Study Scenarios

Table 10 includes the assumptions reflecting the market conditions that are needed to consider while developing the various manufacturing scenarios.

Alternative Scenarios

Each scenario is based on different assumptions reflecting the market conditions that needed to be considered while developing these scenarios. Researchers wanted to quantify the impact of key assumption in order to assess their actual impact on profitability. These scenarios represent actual market conditions for a more realistic reflection of the market in Egypt.

Table 10 Basic assumptions reflecting the market conditions while developing the various scenarios

	Description	Income
Production capacity	6000	Will work 26 days per month for 11 months per year
Number of units sold		It is a percentage from the production capacity
Price LE	12.81	Price per piece $0.845, conversion rate: 15LE
Annual increase	10%	Increase of selling price and costs covering inflation rate mainly
		Establishment expenses
Paid once	Legal	Professional License Fees
	Equipment	Equipment costs
	Furniture	Offices furniture
		Operational costs
Building & utilities	18,000	Rent of building per month
	11,440	Electricity
	13,312	Utilities oil & water repellent 13,312 EGP/month
Raw materials	70,000	Raw Materials (delivered to your door steps) 14,000 per ton * 5 tons per month, increasing cost by 10%
Manpower	26,000	Gross salary per month (including insurance,..) for 2 workers + 1 sales + 1 Maintenance & Production + security + helping hand. Assuming no salary increase
COGS		Sum of the above mention expenses
Offer heads	5%	Management & Administrative costs (covering management expenses), which is 5% of COGS
Marketing	0.5%	Marketing, which is 0.5% of COGS
Others	0.5%	Extraordinary expenses (might include insurance)
Running costs		Total Operational Expenses
		Total costs
Taxation	22%	Taxation rate is 22% of gross profit
Depreciation	20%	Depreciation of equipment and office furniture is unified at 20% (over 5 years period)

First scenario: The base case where no changes were applied to any of the relevant factors as shown in Table 11.
Second scenario: Extending the shift of the workers to 10 h with over time as shown in Table 12.
Third scenario: Having two shifts, each last for 16 h as shown in Table 13.
Fourth scenario: The base case was applied considering the elasticity of demand where the price lowered to $0.2 which is equivalent to 3 LE as shown in Table 14.
Fifth scenario: Besides lowering the price to $0.2, the entrepreneur can also seek financial support from Egyptian government where this amount might cover the rental for 5 years as shown in Table 15.

After applying deep study to the five scenarios, it was found that having financial support was the best decision of all. This fact is very valuable as it proves the support needed to encourage entrepreneurs to get involved in producing eco-friendly products. As the profit margin is high, it is an excellent choice for entrepreneurs seeking to produce an eco-friendly product recycling agriculture wastes.

Tables 11, 12, 13, 14, and 15 detail the assumption and the gain/loss of each scenario.

The base case scenario was modelled using Powersim software which has different simulation tools covering all the needs when building simulations, risk analyses, and optimization [28] as shown in Fig. 6. Different business strategies will be tested to decide the best scenario that suits the expected demand in the market relative to the production constraints. The simulation tool verified the net gains of bagasse production calculate din the base case.

Selected Indicators for Bagasse (Green Material) Selection

Egypt is a suitable market for producing bagasse tableware products due to the availability of bagasse cultivation and sugar factories in Egypt and the lower labour costs compared to the international markets. Due to the high cost of producing tableware, different scenarios were carried out to analyze all the factors relevant to the project trying to reach the best cost, quality, resources, and revenue. The authors selected the manufacturing cost economic attribute. The economic model is based on using local bagasse waste instead of using imported treated bagasse sheets. They also selected the environmental indicator which is highlighted in saving the energy all through the manufacturing process and the reuse of resources. Moreover, the mentioned bagasse production process uses 43 MJ to produce 1 kg of bagasse paste (and the other additives ready for producing a plate), while the energy required to produce 1 kg of Styrofoam is 90 MJ [29]. The manufacturing process is designed to use recycled water to decrease the energy consumption. Additionally, the production concept is based on circular economy which fits well with the environmental attribute based on solid waste production and use of recycled materials. The authors did not define profits as the main criterion of the business success. They placed great emphasis on life-cycle environmental impact of table ware products. The life cycle assessment for bagasse indicated less carbon dioxide release when compared with petroleum-based plastics. The authors selected the bagasse waste due to its suitable mechanical properties for the packaging application. The selection of material in the business model was based on environmental and social perspectives to ensure recyclability and reusability of the products and enhance their sustainability. Bagasse is an eco-friendly product that enjoys many benefits. It is a renewable resource since it is extracted from sugarcane so sugarcane can grow very rapidly and its sustainable resource that is why we are

Table 11 Base case scenario (1st scenario)

Feasibility study	Base case		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
	Description	Income					
Production capacity	6000	Will work 26 days per month for 11 months per year	312,000.00	1,716,000	1,716,000	1,716,000	1,716,000.0
Number of units sold		It is a percentage from the production capacity		75%	80%	85%	85%
Price LE	12.81	Price per piece $0.845, conversion rate: 15LE	12.81	12.81	14.091	15.5001	17.05011
Annual increase	10%	increase of selling price and costs covering inflation rate mainly					
Total income		Total income	3,996,720	16,486,470	19,344,125	22,608,446	24,869,290
		Establishment expenses					
Paid once	Legal	Professional license fees	20,000	NA			
	Equipment	Equipment costs	947,000				
	Furniture	Offices furniture	5000				
	Fixed assets	Total fixed costs	972,000				
		Operational costs					
Building & utilities	18,000	Rent of building per month	108,000	216,000	237,600	261,360	287,496.0
	11,440	Electricity	68,640	137,280	137,280	137,280	137,280.0
	13,312	Utilities oil & water repellent 13,312 EGP/month	79,872	159,744	159,744	159,744	159,744.0
Raw materials	70,000	Raw materials (delivered to your doorsteps) 14,000 per ton * 5 tons per month, increasing cost by 10%	210,000	770,000	847,000	931,700	1,024,870.0
Manpower	26,000	Gross salary per month (including insurance,.) for 2 workers + 1 sales + 1 Maintenance & Production + security + helping hand. Assuming no salary increase	52,000	312,000	312,000	312,000	312,000.0
COGS		Sum of the above mention expenses	518,512	1,595,024	1,693,624	1,802,084	1,921,390.0

Table 11 (continued)

Feasibility study	Base case		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
Offer heads	5%	Management & administrative costs (covering management expenses), which is 5% of COGS	25,926	79,751.2	84,681	90,104.2	96,069.5
Marketing	0.5%	Marketing, which is 0.5% of COGS	0	7975.12	8,468	9010.42	9,607.0
Insurance		Insurance	0	0	0	0	-
Others	0.5%	Extraordinary expenses (might include insurance)	25,926	79,751	84,681	90,104	96,070
Running costs		Total operational expenses	570,363	1,762,502	1,871,455	1,991,303	2,123,136.0
		Total costs					
			1,542,363	1,762,502	1,871,455	1,991,303	2,123,136
		Gross profit	2,454,357	14,723,968	17,472,670	20,617,143	22,746,154
Taxation (22%)	22%	Taxation	539,958.50	3,239,273.07	3,843,987	4,535,771.47	5,004,154.0
Depreciation (20%)	20%	Depreciation of equipment and office furniture		189,400	189,400	189,400	189,400.0
		Net gains (losses)	1,914,398	11,295,295	13,439,283	15,891,971.57	17,552,600.5

Table 12 Extending the shift of the workers to 10 h with over time (2nd scenario)

Feasibility study	Extended shift						
			Year 0 (4 month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
	Description	Income					
Production capacity	7500	Will work 26 days per month for 11 months per year	390,000	2,145,000	2,145,000	2,145,000	2,145,000.0
Number of units sold		It is a percentage from the production capacity		75%	80%	85%	85%
Price LE	4.5	Price per piece $0.300, conversion rate: 15LE	4.5	4.5	4.95	5.445	5.9895
Annual increase	10%	Increase of selling price and costs covering inflation rate mainly					
Total income		Total income	1,755,000	7,239,375	8,494,200	9,927,596	10,920,356
		Establishment expenses					
Paid once	Legal	Professional license fees	20,000	NA			
	Equipment	Equipment costs	947,000				
	Furniture	Offices furniture	5000				
	Fixed assets	Total fixed costs	972,000				
		Operational costs					
Building & utilities	18,000	Rent of building per month	108,000	216,000	237,600	261,360	287,496.0
	11,440	Electricity	68,640	137,280	137,280	137,280	137,280.0
	16,632	Utilities oil & water repellent 13,312 EGP/month + 3320 for the extra 2 h	99,792	199,584	199,584	199,584	199,584.0
Raw materials	77,000	Raw materials (delivered to your doorsteps) 14,000 per ton * 5 tons per month, increasing cost by 10%	231,000	770,000	847,000	931,700	1,024,870.0

Table 12 (continued)

Feasibility study	Extended shift						
Manpower	29,800	Gross salary per month (including insurance,..) for 2 workers + 1 sales + 1 maintenance + security + helping hand. Assuming no salary increase. Assuming 3800 LE is overtime for the staff	59,600	357,600	357,600	357,600	357,600.0
COGS		Sum of the above mention expenses	567,032	1,680,464	1,779,064	1,887,524	2,006,830.0
Offer heads	5%	Management & administrative costs (covering management expenses), which is 5% of COGS	28,352	84,023.2	88,953	94,376.2	100,341.5
Marketing	1%	Marketing, which is 2% of COGS	0	8402.32	8,895	9437.62	10,034.2
Insurance		Insurance	0	0	-	0	-
Others	0.5%	Extraordinary expenses (might include insurance)	28,352	84,023	88,953	94,376	100,342
Running costs		Total operational expenses	623,735	1,856,913	1,965,866	2,085,714	2,217,547.2
		Total costs					
			1,595,735	1,856,913	1,965,866	2,085,714	2,217,547
		Gross profit	159,265	5,382,462	6,528,334	7,841,882	8,702,809
Taxation (22%)	22%	Taxation	35,038.26	1,184,141.70	1,436,234	1,725,214.09	1,914,617.9
Depreciation (20%)	20%	Depreciation of equipment and office furniture		189,400	189,400	189,400	189,400.0
		Net gains (losses)	124,227	4,008,921	4,902,701	5,927,268.14	6,598,790.8

Table 13 Two shifts, each last for 16 h (3rd scenario)

Feasibility study	2 shifts		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
	Description	Income					
Production capacity	12,000	Will work 26 days per month for 11 months per year	624,000.00	3,432,000	3,432,000	3,432,000	3,432,000.0
Number of units sold		It is a percentage from the production capacity		75%	80%	85%	85%
Price LE	4.5	Price per piece $0.845, conversion rate: 15LE	4.5	4.5	4.95	5.445	5.9895
Annual increase	10%	Increase of selling price and costs covering inflation rate mainly					
Total income		Total income	2,808,000	11,583,000	13,590,720	15,884,154	17,472,569
		Establishment expenses					
Paid once	Legal	Professional license fees	20,000	NA			
	Equipment	Equipment costs	947,000				
	Furniture	Offices furniture	5000				
	Fixed assets	Total fixed costs	972,000				
		Operational costs					
Building & utilities	18,000	Rent of building per month	108,000	216,000	237,600	261,360	287,496.0
	11,440	Electricity	68,640	137,280	137,280	137,280	137,280.0
	26,624	Utilities oil & water repellent 13,312 EGP/month for one shift	159,744	319,488	319,488	319,488	319,488.0
Raw materials	140,000	Raw materials (delivered to your doorsteps) 14,000 per ton * 5 tons per month, increasing cost by 10%, multiply by 2 for 2 shifts	420,000	770,000	847,000	931,700	1,024,870.0
Manpower	28,000	Gross salary per month (including insurance,..) for 4 workers + 1 sales + 1 maintenance + 2 security + helping hand. Assuming no salary increase	56,000	336,000	336,000	336,000	336,000.0
COGS		Sum of the above mention expenses	812,384	1,778,768	1,877,368	1,985,828	2,105,134.0

Table 13 (continued)

Feasibility study	2 shifts		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
Offer heads	5%	Management & administrative costs (covering management expenses), which is 5% of COGS	40,619	88,938.4	93,868	99,291.4	105,256.7
Marketing	1%	Marketing, which is 2% of COGS	0	8893.84	9,387	9929.14	10,525.7
Insurance		Insurance	0	0	-	0	-
Others	0.5%	Extraordinary expenses (might include insurance)	40,619	88,938	93,868	99,291	105,257
Running costs		Total operational expenses	893,622	1,965,539	2,074,492	2,194,340	2,326,173.1
		Total costs					
			1,865,622	1,965,539	2,074,492	2,194,340	2,326,173
		Gross profit	942,378	9,617,461	11,516,228	13,689,814	15,146,396
Taxation (22%)	22%	Taxation	207,323.07	2,115,841.50	2,533,570	3,011,759.09	3,332,207.2
Depreciation (20%)	20%	Depreciation of equipment and office furniture		189,400	189,400	189,400	189,400.0
		Net gains (losses)	735,055	7,312,220	8,793,258	10,488,654.97	11,624,789.1

Table 14 Base case + price sensitivity (lowering the price to $0.2 = 3 LE) (4th scenario)

Feasibility study	Base-price sensitivity		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
	Description	Income					
Production capacity	6000	Will work 26 days per month for 11 months per year	312,000.00	1,716,000	1,716,000	1,716,000	1,716,000.0
Number of units sold		It is a percentage from the production capacity		75%	80%	85%	85%
Price LE	3	Price per piece $0.845, conversion rate: 15LE	3	3	3.3	3.63	3.993
Annual increase	10%	Increase of selling price and costs covering inflation rate mainly					
Total income		Total income	936,000	3,861,000	4,530,240	5,294,718	5,824,190
		Establishment expenses					
Paid once	Legal	Professional license fees	20,000	NA			
	Equipment	Equipment costs	947,000				
	Furniture	Offices furniture	5000				
	Fixed assets	Total fixed costs	972,000				
		Operational Costs					
Building & utilities	18,000	Rent of building per month	108,000	216,000	237,600	261,360	287,496.0
	11,440	Electricity	68,640	137,280	137,280	137,280	137,280.0
	13,312	Utilities oil & water repellent 13,312 EGP/month	79,872	159,744	159,744	159,744	159,744.0
Raw materials	70,000	Raw materials (delivered to your door-steps) 14,000 per ton * 5 tons per month, increasing cost by 10%	210,000	770,000	847,000	931,700	1,024,870.0
Manpower	17,000	Gross salary per month (including insurance,,,) for 2 workers + 1 sales + 1 maintenance + security + helping hand. Assuming no salary increase	34,000	204,000	204,000	204,000	204,000.0

Table 14 (continued)

Feasibility study	Base-price sensitivity		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
COGS		Sum of the above mention expenses	500,512	1,487,024	1,585,624	1,694,084	1,813,390.0
Offer heads	5%	Management & administrative costs (covering management expenses), which is 5% of COGS	25,026	74,351.2	79,281	84,704.2	90,669.5
Marketing	1%	Marketing, which is 2% of COGS	0	7435.12	7,928	8470.42	9,067.0
Insurance		Insurance	0	0	-	0	-
Others	0.5%	Extraordinary expenses (might include insurance)	25,026	74,351	79,281	84,704	90,670
Running costs		Total operational expenses	550,563	1,643,162	1,752,115	1,871,963	2,003,796.0
		Total costs					
			1,522,563	1,643,162	1,752,115	1,871,963	2,003,796
		Gross profit	- 586,563	2,217,838	2,778,125	3,422,755	3,820,394
Taxation (22%)	22%	Taxation	(129,043.90)	487,924.47	611,188	753,006.14	840,486.6
Depreciation (20%)	20%	Depreciation of equipment and office furniture		189,400	189,400	189,400	189,400.0
		Net gains (losses)	(457,519)	1,540,514	1,977,538	2,480,349.04	2,790,507.2

Table 15 Base case + price sensitivity (lowering the price to \$0.2 = 3 LE) + grant covering rental for 5 years (5th scenario)

Feasibility study	grant covering rental		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
	Description	Income					
Production Capacity	6000	Will work 26 days per month for 11 months per year	312,000.00	1,716,000	1,716,000	1,716,000	1,716,000.0
Number of units sold		It is a percentage from the production capacity		75%	80%	85%	85%
Price LE	3	Price per piece \$0.845, conversion rate: 15LE	3	3	3.3	3.63	3.993
Annual increase	10%	Increase of selling price and costs covering inflation rate mainly					
Total income		Total income	936,000	3,861,000	4,530,240	5,294,718	5,824,190
		Establishment expenses					
Paid once	Legal	Professional license fees	20,000	NA			
	Equipment	Equipment costs	947,000				
	Furniture	Offices furniture	5000				
	Fixed assets	Total fixed costs	972,000				
		Operational costs					
Building & utilities	0	Rent of building per month	0	0	-	0	-
	11,440	Electricity	68,640	137,280	137,280	137,280	137,280.0
	13,312	Utilities oil & water repellent 13,312 EGP/month	79,872	159,744	159,744	159,744	159,744.0
Raw materials	70,000	Raw materials (delivered to your doorsteps) 14,000 per ton * 5 tons per month, increasing cost by 10%	210,000	770,000	847,000	931,700	1,024,870.0
Manpower	17,000	Gross salary per month (including insurance,..) for 2 workers + 1 sales + 1 maintenance + security + helping hand. Assuming no salary increase	34,000	204,000	204,000	204,000	204,000.0

Table 15 (continued)

Feasibility study	grant covering rental		Year 0 (4-month installation + 2 months trial production)	Year 1	Year 2	Year 3	Year 4
COGS		Sum of the above mention expenses	392,512	1,271,024	1,348,024	1,432,724	1,525,894.0
Offer heads	5%	Management & administrative costs (covering management expenses), which is 5% of COGS	19,626	63,551.2	67,401	71,636.2	76,294.7
Marketing	1%	Marketing, which is 2% of COGS	0	6355.12	6,740	7163.62	7,629.5
Insurance		Insurance	0	0	-	0	-
Others	0.5%	Extraordinary expenses (might include insurance)	19,626	63,551	67,401	71,636	76,295
Running costs		Total operational expenses	431,763	1,404,482	1,489,567	1,583,160	1,686,112.9
		Total costs					
			1,403,763	1,404,482	1,489,567	1,583,160	1,686,113
		Gross profit	- 467,763	2,456,518	3,040,673	3,711,558	4,138,077
Taxation (22%)	22%	Taxation	(102,907.90)	540,434.07	668,948	816,542.76	910,376.9
Depreciation (20%)	20%	Depreciation of equipment and office furniture		189,400	189,400	189,400	189,400.0
		Net gains (losses)	(364,855)	1,726,684	2,182,325	2,705,615.22	3,038,300.0

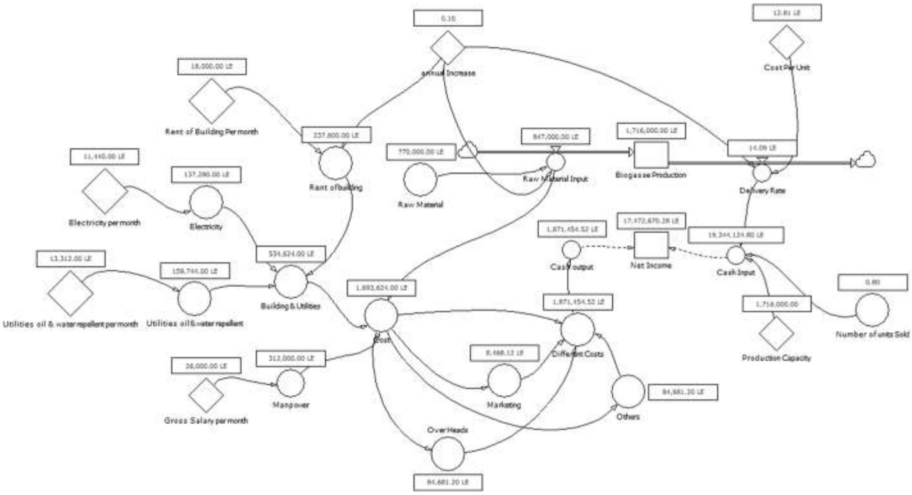


Fig. 6 Powersim Model for investment decision support

making product from bagasse those products will be sustainable for the future generation and have no impact on our limited natural resource [30]. Bagasse is not harmful since it doesnot contain CO2 free because the whole production is free to harmful and after using these products we do not need to incineration because these products are biodegradable. It is a substitute for plastic because it is made from degradable materials and it is not harmful to soil after it degraded within a few months.

On the contrary, traditional plastic tableware factory generates more toxic emissions (nickel, ethylbenzene, ethylene oxide, benzene) to air, water, and soil than baggage-based tableware factory. It can be hazardous to workers as serious accidents may include explosions, chemical fires, and spills. It was found that many chemical additives that are usually used to give plastic products desirable performance properties have sever negative environmental effects on both human and animal [31]. The abovementioned negative impacts are only few of the actual negative effect of plastic products on the environment, animals, and humankind.

Besides, the production of tableware form bagasse follows the concept of circular economy and sustainability since it accomplishes the cradle-to-cradle concept and avoids landfilling of bagasse waste. This new introduced manufacturing process focuses on returning waste materials back to the production processes and closing the loop of materials. Additionally, the idea of exchanging of waste materials among industries is highlighted in this manufacturing process since the raw material of bagasse pulp is commonly used in paper making. However, the use of paper is declining due to the advanced technology. The authors believe that the solution presented in this work is a sustainable solution due to the large amounts of sugarcane waste available in Upper Egypt [32].

Conclusion

This paper discussed the production of tableware made of sugarcane bagasse. The results show that bagasse is a superior choice for producing pulp tableware from the aspects of energy, resource efficient utilization, economic added value, and environmental protection. The investment cost for starting this manufacturing plant is estimated to be less than 1 million EGP, in addition to a monthly cost of around 132,000 EGP. Moreover, the cost of manufacturing tableware using bagasse is estimated to be 1.5 times the cost of the current Styrofoam tableware.

This leads us to suggest that the production facility should be established in Upper Egypt near the location of the raw materials to maximize the environmental and social impact of this project, and also, it can go green all the way, promoting environmental sustainability using solar energy and recycling water. Such a direction can assist the project to be financed with a green loan. The project will also have a favourable social impact on its nearby community in the form of employing youth and utilizing local SMEs for logistic services. This project can be a role model replicated in many other governorates in Egypt.

As part of future research, we intend to do more experiments with other raw materials as well as other natural fibres so we could have a more comprehensive idea about multiple alternatives to traditional plastic.

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Data Availability Data is available upon request.

Declarations

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Consent to Participate Not applicable.

Consent to Publish Not applicable.

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