AMERICAN UNIVERSITY OF BEIRUT

CIRCULAR ECONOMY IN LEBANESE GLASS INDUSTRY

by
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ABSTRACT
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Keywords: Glass recycling, Lebanon, Flat glass, Bottle glass, Solar panel glass, Glass waste, Optimization, NPV.

Glass waste disposal is one of the main challenges that face humans nowadays because of its impact on the environment and the areas of the landfills. It is a non-biodegradable material. This problem and the deficit in the glass trade balance, and the difficulty of import or export nowadays in Lebanon tends to create a problem. The need to solve these problems pushes Lebanon toward glass recycling. The Lebanese glass industry should cut the amount of yearly glass waste, step closer toward self-sufficient, decrease trade balance in the glass industry, and reduce pollution. However, because there is no previous successful experience in Lebanon's glass recycling field, the whole process must be studied. Under the supervision of international expertise in the recycling field, in cooperation with Elite Glass Co., and following the cognitive analytics management framework, a linear programming model was created for optimizing the input of the raw materials that must be introduced in the recycling process under several technical constraints to produce new glass products. The final product alternatives were flat glass, bottle glass, and solar panel glass. The profitability of the projects was studied under the net present value (NPV) model.

The results showed that it is feasible to have a glass recycling manufacturer in Lebanon and suitable for all manufacturing sizes, which means that it is easy to enter the recycling field with the glass industry's support.

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CHAPTER I

INTRODUCTION

The management dilemma of solid waste, especially glass waste, is finally recognized and tackled worldwide. In countries like the USA, recycling schemes were implemented to collect glass that can be recycled to break them into smaller pieces called cullet, then delivered to recycling plants where they get crushed, sorted, cleaned, and mixed with raw materials to produce new bottles, jars ready to use [1]. However, the problem is still hindered by social and economic predicaments and priorities in developing countries. In Arab regions, solid waste generation has become an increasingly important environmental issue over the last decade due to the increase in populations and change in lifestyles leading to new trends of unsustainable consumption patterns resulting in waste products like glass waste. Such increases in solid waste generation synchronous with shifting characteristics pose numerous concerns regarding conventional waste management systems' sufficiency and their associated environmental, economic and societal implications. For example, a prediction regarding the amounts of municipal solid wastes generated in the Arab Region within the year 2020 shows that solid waste can exceed 200 million tons per annum [2]. Glass waste is found in municipal solid wastes as containers (bottles, jars and flat glass). Lebanon produces 2,040,000 tons of Municipal Solid Waste (MSW) per year, with 5.6 million people [3]. Lebanon falls behind due to implementing an insufficient solid waste management strategy, mainly based on bailing, wrapping and landfilling, with inadequate sorting and little composting. This deficient solid waste management system costs around US$ 130 million per year, which is substantially high to the point that municipalities are starved of funds for other municipal services. Therefore, the public and private sectors are interested more than ever in adopting an integrated solid waste management strategy, which falls under the concept of the circular economy.

The circular economy is an economic system aimed at eliminating waste and the continual use of resources [4]. Circular systems employ reuse, repair, remanufacture, and recycle manufactured products to create a closed-loop system, minimize the use of new resources and reduce waste, pollution and carbon emissions [5]. The circular economy aims to keep products, equipment and infrastructure in use for longer, thus improving these resources' productivity. All "waste" should become "food" for another process: either a by-product or recovered resource for another industrial process. A circular economy approach provides a framework for designers and engineers to build a greener, more sustainable glass industry—projects which help economic growth without depending solely on finite resource consumption [6], in an interview with Dr. Imad Hoballah, the minister of industry, on June 15, 2020. Dr. Hoballah mentioned that solar energy production and the glass industry are the best two out of five potential industries for Lebanon's investment to achieve self-sufficiency.

In the context, "Elite Glass" is one of the glass industries in Lebanon. It imports glass sheets and cut them into different sizes to meet market demands. The cutting process generates a reasonable amount of glass waste yearly because of the difference in customers' dimension orders and failed products. Due to the current situation and the associated difficulty in importing standard glass sheets and the availability of hundreds of tons of waste glass, the management would like to explore a circular economy's potential to sustain their business.

Furthermore, Lebanon's glass industry is now facing additional challenges after the Beirut port explosion on August 4, 2020. The glass was retrieved from Beirut after the massive blast was sent from Beirut to Tripoli (North Lebanon) to be recycled and reused; however, the broken glass could not be treated in Beirut nor collected wisely.

Elite Glass Co. and the glass industry in Lebanon produce a massive amount of glass waste without proper waste management strategy; thus, implementing a circular economy in the glass industry starting with Elite Glass Co. will contribute to reducing and recycling glass waste in Lebanon and develop a greener and sustainable glass industry.

The thesis's main objectives are to understand the glass business context—first, the potential of glass recycling at "Elite Glass" and Lebanon. Second, consider the various options available to recycle the existing glass waste into various product options. Third, recommend the best combination of production options for the management to implement. Finally, the thesis will follow the cognitive analytics management process to address the glass waste challenge and create a sustainable glass industry business.

This dissertation intends to investigate the potential of glass recycling at "Elite Glass" and Lebanon and suggest a circular economy approach to reduce and reuse glass waste due to,

- The massive availability of glass wastes in Lebanon, estimated at around 71,400 tons per year in 2014 [7].
- According to Lebanon customs, the local demand exceeds available supplies in the glass industry ($ 90 million per year).

- The solid wastes are not biodegradable and occupy large green areas with potential solar rays' reflections.
- The economic crisis slows down the payment for imported materials ($ payment & other import restrictions).

The questions below provide further clarity on this matter:

a. What is the Lebanese situation in the glass recycling industry?

   This question will lead the research towards statistics that will help assess Lebanon's solid waste management strategy and provide adequate measures for implementation as stated in objectives one and two.

b. What is the glass waste capacity of Elite Glass?

   This question will help understand the glass business context at Elite Glass Co., as mentioned in objective one.

c. What components and how much must be added from each component to match each product's qualification?

   This question will help provide a transparent image of the best product composition, as expressed in objective three.

d. What is the optimal mix of each product that can be produced in order to maximize the profit?

   This question will lead to further elaboration on the best combination of production and select the top-notch mix options of each recycled product, as expressed in objective three.

e. What is the best product to produce?

Answering this question will guide Elite Glass Co. and the glass industry in general towards achieving sustainable glass industry business as in objective four.

This research is on glass waste management (reduce, recycle, and reuse). It offers a revolutionary approach towards tackling glass waste and solid waste in general without damaging the economy. According to the Ministry of Production, the implementation of a circular economy in the glass industry contributes to the national strategy for the Top 5 New Manufacturing in Needs for Lebanon (Glass; Solar Energy; Containers; Electric Bikes; Microbuses). Addressing Elite and National glass waste management help close the shortage in glass supply and produce new glass products to meet the Lebanese and regional demands (bottles, solar panels, flat glass for constructions). This approach creates the potential to transform Elite Glass into regional suppliers of glass products. Furthermore, it expands the import of glass waste locally and then exports them as a new same or different product. Finally, it creates new jobs with various skills (Businesses, Drivers; Engineers; Technicians).

This study has a series of potential limitations:

- Struggling to find previous studies that show accurate statistics regarding glass waste management in Lebanon since proper waste management in Lebanon has only been recently discussed.
- Lebanon has little experience in glass recycling and a few active recycling plants. Therefore the Lebanese glass industry could not provide Lebanese glass recycling models or contribute to glass waste management.

- As a student in charge of collecting data, analyzing statistics, and searching for scholars and references, it was hard to find these many valuable resources, especially when building new connections is challenging.

The study's scope addresses the glass waste management issue at Elite Glass Co. and Lebanon in general. By estimating the capacity of waste management projecting circular economy in the glass industry, reducing and recycling measures to tackle glass waste, and introducing a proper solid waste management strategy to sustain the Elite Glass Co. and the Lebanese glass industry business. Therefore, the dissertation includes specific and narrow objectives that suit the Elite Glass Co. and the Lebanese glass industry and aren't necessary applicable in other Arab regions. Although the study mentioned that glass waste is part of solid waste management, the measures stated to reduce and recycle glass waste are not necessary suitable for all kinds of solid wastes.

The following terms and definitions apply for this dissertation.

i. Solid waste: "Solid waste means any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations, and from community activities." [8]

ii. Municipal solid waste: "Commonly known as trash or garbage—consists of everyday items we use and then throw away, such as furniture, clothing, bottles, food scraps, appliances, and batteries. This comes from our homes, schools, hospitals, and businesses." [9]

iii. Float glass: “plate glass made by allowing it to solidify on a layer of molten metal.” [10]

iv. Optimal mix: “maximizes the potential unit sales while maintaining -- or ideally improving -- the company's profitability” [11]

CHAPTER II

LITERATURE REVIEW

Scholars who contribute to the glass recycling field have conducted much research to propose different solutions and models. The research on glass recycling provides a literature explanation of the glass waste management issue. Although the literature covers various solutions and models, this review will discuss six major themes that will sum up the problem and provide a panoramic view. The six major themes are the culture, benefits, process of glass recycling, the preparation and standards of cullet glass, the final products of glass recycling (bottles, flat glass, and solar panels), and reading on Lebanon's glass market. This literature will present these themes through various contexts and focus on their application to the glass industry's circular economy.

A. Glass-Recycling Culture

Countries like Lebanon with low glass-recycling rate pales compared with Switzerland's 90% glass-recycling rate. Joseph J. Cattaneo, the executive director of the Glass Packaging Institute (GPI), a trading association on behalf of the North American glass container industry, stated that recycled glass is an ingredient of the recipe of new glassmaking [12]. Manufactures also agree that the usage of cullet benefits the glass industry, environment and consumers. However, Lebanon falls behind despite the nongovernmental initiatives that promote sorting and recycling, like sorting at the source implemented by DPNA in Saida, South Lebanon. Unlike the Lebanese government and society, Swiss people teach their children about recycling habits at home and in schools. The Swiss government also legislates policies to promote practices of recycling. Another factor that encourages Europeans to maintain high recycling rates is the high cost of trashing glass in landfills, which are more expensive than recycling. Therefore, the glass-recycling rate differs enormously between the European counties and Lebanon.

The European glass-recycling model (figure 1.a) compared to the Lebanese glass waste, dumped in the waste landfills with metal, paper, and organic waste (figure 1.b).

Figure 1 European Glass-Recycling Model

Figure 5 Mixed Waste Landfill in Lebanon

B. Glass-Recycling Benefits

Glass is one of the most popular and most accessible commodities to recycle and reuse to conserve natural resources and green areas. The benefits of recycling glass identify as follow [13] :

- Demands less energy: energy costs drop to 2-3% for every cullet used while manufacturing since recycled glass melts at a lower temperature than raw materials.
- Cuts down carbon dioxide emissions: Using six tons of recycled glass containers reduce a ton worth of carbon dioxide.
- It does not process by-products: glass recycling is a closed circular system that does not produce waste.

- Save raw materials: each ton of recycled glass conserves over a ton of natural resources, including sand, soda ash, limestone, and feldspar.
- Extend furnace life: adding cullet in the manufacturing mix makes it less corrosive and prolongs furnace life.
- Aid the environment: recycling glass provides significant environmental changes.

C. Glass Recycling Process

Recycling glass is a process that restores used materials or products to transform them into either the same product or a secondary product. The recycling process is classified into two different categories: open and closed recycling loops. Closed-loop recycling is taking unusable products recycling it into the same old product. While open loop recycling means different outputs, in other words, inputs (primary products) transform into a different kind of product (secondary product).

Manufacturing glass from recycled glass is a two-step process before molding it into different forms.

The first step is batch mixing; recycling manufacturers collect used glass from homes, offices and recycling sites and send them to material recycling facilities to sort them into different colors. Next, they crush the separated glass to form a new material called cullet.

After batch mixing starts the batch melting, the point at when the ingredient mixture is fed to the furnace. The final step is shaping and molding the glass into the required form (flat or container glasses).

1. Cullet Preparation and Standards

a. <u>Process:</u>

To prepare cullet at waste recycling facilities, they bring in pure glass (after collecting and sorting used glass) and put it in a cullet crusher, which turns glass into tiny pieces. This activity takes half a day before the melted batch of glass is ready. The cullet is then weighed for 2-3 hours according to the required quantity of the final glass.

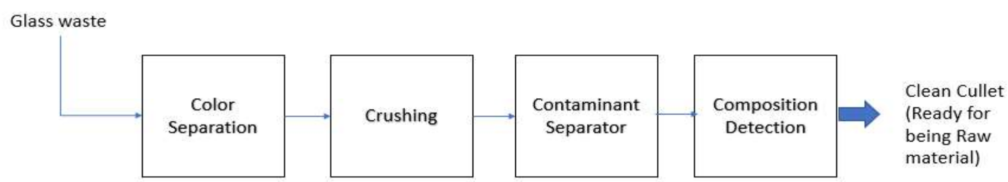

Figure 6 Cullet Preparation

The weighed cullet is then mixed with other ingredients (major and minor) for less than an hour and poured into the furnace to melt and get ready to shape glass [13].

b. <u>Standards</u>

Each type of cullet has its composition. The cullet used in this research is composed as follows,

	CFE	CFM	CBM
SiO2	72.6	72.07661	70.85427
Na2O	13.2	7.056452	14.07035
CaO	9.6	8.921371	5.527638
MgO	3.1	4.032258	5.527638
Al2O3	1.5	0.756048	4.020101
Fe2O3	0	0.100806	0
K2O	0	7.056452	0

Table 1: Estimated Percentage of chemical raw materials found in glass waste cullet in elite glass cullet (CFE), market flat glass cullet (CFM) (Ref: WRAP) or market bottle glass cullet (CBM) [Ref: E708-79]

2. *Final products*

Treating glass waste produces usable quality products. This research selected three different products to investigate further after analyzing the market demands and capabilities.

a. Flat Glass

i. Process

Pilkington Brothers originally developed the float glass process in 1959, the most common manufacturing flat glass sheet. The global production of float glass usage in the construction industry is more than 80-85% [14]. Glass is the most preferred construction material in modern buildings due to its unique and fascinating physical, optical, chemical and thermal properties. It makes buildings bright, airy, energy-efficient, and it enhances the comfort of the apartment owner.

The float glass process includes ingredients such as silica, lime and soda. First, the ingredients are blended with cullet and heated in a furnace at 1600°C to form molten Glass. Second, the molten Glass floats on a tin bath under controlled heat to form thickness. At the end of the tin bath, the Glass slowly cools down and passes through the annealing lehr [13]. The market usually offers flat glass sheets of thickness 2–22 mm, but thicker Glass would be available.

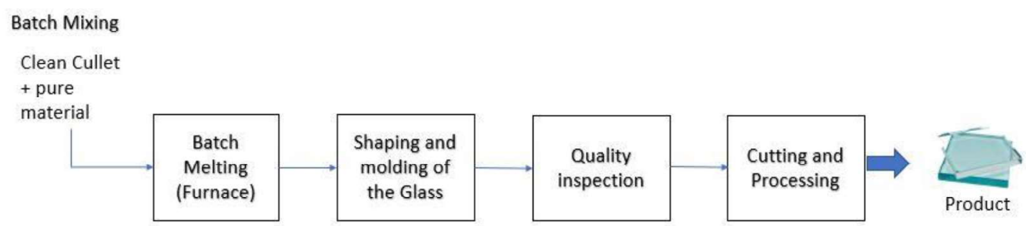

Figure 7 Flat Glass Production

ii. Standards

Recycled flat glass standards are based on "plain clear" glass type, which Elite Glass Co. uses and many other glass companies in Lebanon.

This type of glass apply the (BS EN 572) standards, as following,

	Min	**Max**
SiO2	68.53715999	74.96251874
Na2O	9.974927884	16.04076241
CaO	4.897228169	14.13200129
MgO	0	6.135986733
Al2O3	0	3.022860382

Table 2:The (BS EN 572) standards

iii. Challenges

Nevertheless, flat glass recycling does not apply to all flat glass kinds. For example, the total effort to produce cullet out of scrap car glass is very high. In order to recycle scrap car glass, the manufacturers go through several exhausting steps. The steps are linked to high logistics effort and hard work. Recycling cullet from scrap cars is more expensive than market alternatives and more expensive than making glass from raw materials

b. Bottle Glass

Glass bottles are vitreous silica compounds produced in a suction fed type-blowing machine. Bottles vary in shape, size, and color according to the clients' demand, while almost all bottles have a flat bottom and have a straight neck for sealing. They are produced either in clear, brown or green colors. Standard sizes for glass bottles range between 50 ml to 1,000 ml while typical sizes are 50,100,250,330,500,630,750 and 1,000 ml [15].

i. Process

Container glass making begins with the basic soda lime formulation then melts in a natural fired gas fuel or an electrically heated furnace to 1600C. The molten glass forms into the desired product by individual automated section (IS) machines. During the process, the glass temperature is reduced by 600°C to ensure that the containers are sufficiently solidified when taken away by conveyor. Automatic container manufacture permit bottles and jars production of different sizes, shapes and colors. The bottle production rate depends on the shape of the bottles; the simpler it is, the faster the product; for example, producing lightweight round beer bottles takes 750 /minute. The containers then pass through a continuous annealing oven, where they re-heat at 550°C then cool under certain conditions to prevent further stresses later on.

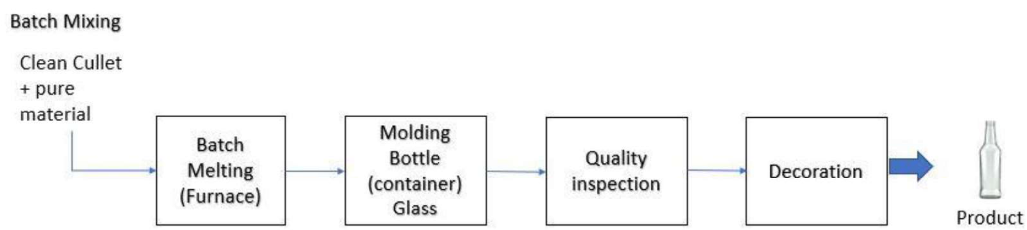

Figure 8 Bottle Production

ii. Standards

Each bottle type has its own composition, the standard and commercial use and that will be used in our research is of following composition

	Min	**Max**
SiO2	66	88
Na2O	8	18
CaO	0	15
MgO	0	5
Al2O3	0	7
Fe2O3	0	0.5
K2O	0	4
So3	0	0.2
Cr2O3	0	0.1

Table 3: The Standards of Bottle Glass According to (CBOT sampling protocols)

iii. Ohio Glass Recycling Model (bottles) [16]

In 2011, the Ohio Department of Natural Resources (ODNR) cooperated with Environmental Services, Inc. (DSM) to analyze the supply and demand for container glass in Ohio. The analysis introduced four new strategies to increase the supply of cullet and meet potential future demand through a container deposit program. First, DSM would like to implement recycling programs at restaurants and bars. The second step is to install drop off locations throughout Ohio to collect and separate Glass by color. The next step is to recover additional plate glass from windshield glass replacement. The final step is to enact container deposit legislation.

c. Solar panels

Solar panels produce clean and renewable energy for home and business and control the use of energy. The solar panel consists of 10 main parts, including flat glass. Thus, manufactures can also use recycled glass in solar panels production.

The manufacturing of solar panels and adding recycled flat glass starts with producing solar cells and combining them using the string machine. Second, the glass loading machine sends the glass to the layup machine with Eva sheets, which protect the solar cells from weather conditions. Third, the glass passes through the El-tester machine to detect the presence of broken Cells, cracked cell, solder failure, short circuit, ribbon shift, and foreign matter detection. Fourth, the free-error glass undergoes lamination to empty the air and melt the Eva. Fifth, the panels are cleaned with alcohol and framed from all sides by aluminum; this process is called framing and sanding.

Finally, the panels pass through Flasher, the panel tester, to check the data and monitor its function before releasing the product [17].

i. Process

If the used glass is recycled and mixed in solar glass panels, then we are recycling and reusing glass and promoting and developing future technologies as part of the culture.

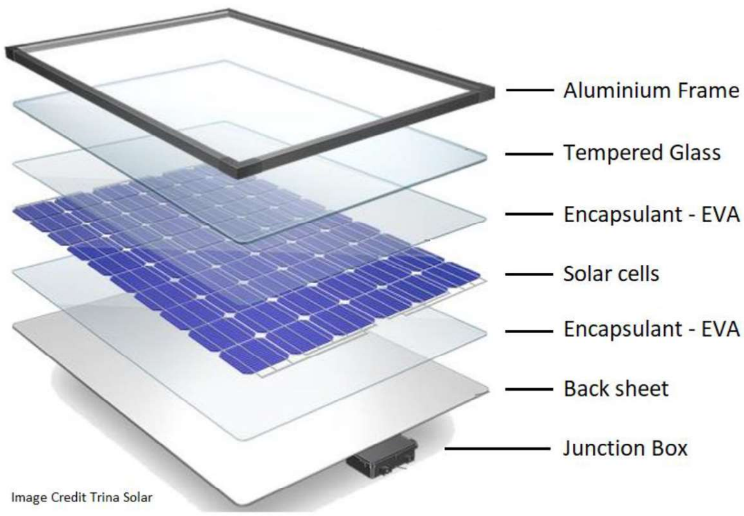

Figure 9 Components of Solar Panel

The process of manufacturing recycled solar panels starts from flat glass production. The glass is layered and loaded then tested. After testing the glass comes lamination, framing and sanding. Finally, the panels go through panel tester to release finalize the product

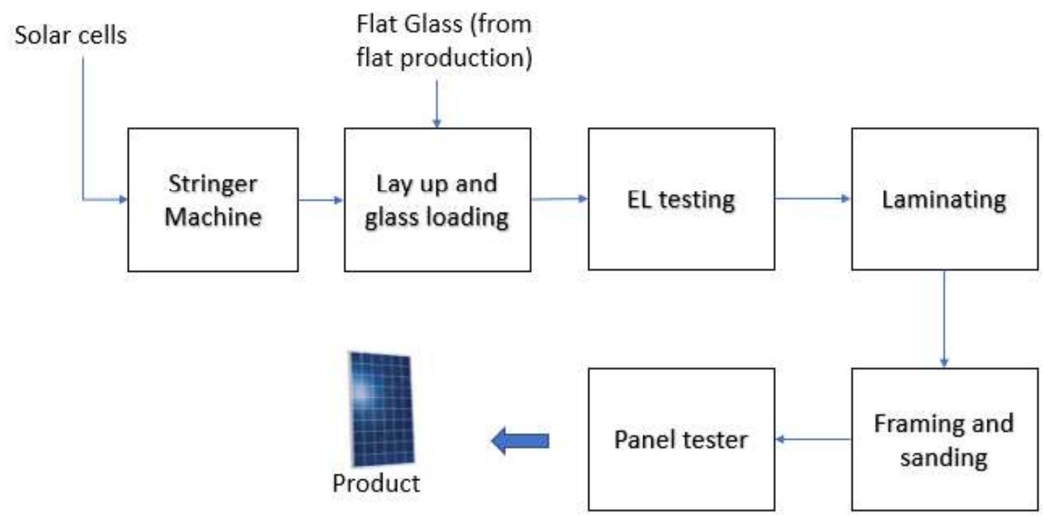

Figure 10 Solar Panels Production

ii. Standards

The flat glass used in Elite Glass Co. (Planiclear glass) has the same glass specifications needed for solar panel production; thus, what applies to flat glass products is also applied for solar panel glass

Thickness (mm)	Light Transmission (%)	Solar Factor g	LRe (%)
2	91	0.90	8
3	91	0.89	8
4	91	0.88	8

Table 4: Plani clear glass characteristics

D. Glass Market in Lebanon

In Lebanon, two leading factories worked in glass recycling [18]. The first one was called Soliver [19], and it was in Chouifat. Due to financial stress, it closed in 2017.

The second one was called Maliban [20]. It was located in Taanayel. During the Israeli war in 2006, it was destroyed. By that, Lebanon lost two examples of the recycling plants.

According to the Lebanese Customs [21], in 2019, Lebanon imports of glass were 153,181 tons with $94.621 million, while exports were 4984 tons with $5.192 million. In 2018, the top partner countries to which Lebanon exports stone and glass are the United Arab Emirates, South Africa, Switzerland, Saudi Arabia [22]. The Middle East & African flat glass market is expected to register an increase in CAGR of over 6% during the forecast period (2020-2025) [23]. The United Arab Emirates (UAE) container glass market is expected to reach a value of $ 252.47 million by 2025, at a CAGR of 2.19%, over the forecast period (2020-2025) [24].

In addition to decreasing the environmental impacts of glass waste and decreasing energy used in the production process, the Lebanese government should consider a way to cover the losses in the economy to fulfill Lebanon's market needs. Therefore, Lebanon should implement reduce, recycle, and reuse measures to manage solid waste management in general and glass waste to provide the market with affordable local recycled glass. The various recycling products, including producing an original standard glass sheet from the recycled product. These product options include flat glass production, bottles for drinking, and the production glass for solar energy.

In conclusion, the studies show that recycling glass has positive impacts on the environment and the economy. European countries like Switzerland and Germany succeeded in tackling the glass waste management issue while social and economic predicaments and priorities still hinder developing countries like Lebanon. However, these countries can still change their situation, contribute to glass waste management on a local level by implementing recycling programs and enact supporting policies legislation. Instead of exporting large amounts of glass, which exceed the local market, demand in Lebanon, the glass industry should consider the various options available to recycle the exiting glass waste into various product options such as bottles, flat glass and solar panels to reduce glass waste and conserve natural resources.

All "waste" should become "food" for another process: either a by-product or recovered resource for another industrial process.

CHAPTER III

METHODOLOGY

In order to take into consideration the whole part of the glass waste problem and Lebanon and the recycling feasibility to solve this challenge , the cognitive analytics management framework introduced by Prof Osman [25] will be adopted for the investigation of the above glass waste recycling challenge. The cognitive process is to understand the various business processes and challenges. The glass production process at Elite Glass will be studied as a case study to determine the current capacity and the yearly waste. The Analytics Process aims to analysis the various best practice options. The various recycling products including the options of producing an original standard glass sheet from the recycled product will be considered. These product options include the production of bottle for drinking; the production of glass for solar energy according to the international standard for each product along with the associated costs of raw materials to add to meet each standard.

For this purpose a product mix model will be developed to determine the optimal mix of each product to produce in order to maximize the profit subject to market and technical constraints.

The management process discusses managerial implication, venture capital requirement, procurement of equipment and material using the net present value (NPV) model which will take these values into consideration.

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A. Machines Alternatives

1. Machines capacities

We have the following machines:

- Two flat glass production machines
- Three bottle glass production machines
- Three solar panel production machines

	Machine 1 Capacity	**Machine 2 Capacity**	**Machine 3 Capacity**
Flat Glass	40 ton/day	200 ton/day	
Bottle Glass	20 ton /day	60 ton/day	120 ton/day
Solar Panel Glass	312 panels /day	720 panels /day	1032 panels /day

Table 5: Available machine's capacities 1

2. Consideration for solar panel glass

a. <u>Capacities in tons per day</u>

Solar Panel production line capacities are measured by solar panel production per day , so to turn that into tons of glass a simple calculation were done :

The standard panel used for our production is the 60 cell, 320 Watt solar panel which has an **area of 1.62 m2** of glass on it

Solar panel use the 4 mm thickness glass which is around 10 Kg /m2

so each panel's glass weight is equal

$$1.62 \times 10 = 16.2 \text{ Kg}$$

Then the capacity in tons /day will be calculated using the following formula

Solar Panel Machine Capacity (glass tons/day) =

one panel's glass weight x nb of panels produced per day

- For example:

For Solar panel Machine 1 (312 Panel per day)

Solar Panel Machine Capacity (glass tons/day) =

312 panel /day x 16.2 Kg /panel = 5,054 Kg /day = 5.05 tons /day

So the capacities table become

	Machine 1 Capacity	Machine 2 Capacity	Machine 3 Capacity
Flat Glass	40 tons/day	200 tons/day	
Bottle Glass	20 tons /day	60 tons/day	120 ton/day
Solar Panel Glass	5.05 tons /day	11.6 tons /day	16.7 tons/day

Table 6:Available machine's capacities 2

b. <u>Solar panel full production line</u>

For the solar panel production machines, they need a flat production machine to produce flat sheet to integrate on the solar panel and the capacity is from the output from the flat production line.

- For example:

  capacity for solar panel machine 1 is 5.05 tons/day , if we combined it with flat machine 1 (40 ton/day) the output will be :

  40 tons the output from the flat production line:

  - 5.05 tons /day will go for solar panel production
  - 34.95 tons/ day will go as flat output (selling as windows or doors)

  Therefore, our alternatives become eleven

  - Two Flat Glass Machines

- Three Bottle Glass Machines
- First Flat Machine (40 tons/day) with each solar machine (Three machines)
- Second Flat Machine (200 tons/day) with each solar machine (Three machines)

B. Mathematical Model

1. Model Definition:

The Glass raw material -mix problem can be formulated as a LP model in which the following must be take into consideration:

- Set of variables to define the quantities of cullet glass and pure materials that must be used to obtain the final glass product according to the standards
- Set of constraints to express the max quantity that can be produced
- A set of constraints to define the lower and upper limits on the available quantities of each final product.
- A linear combination of variables representing the objective function to be minimized.

2. Decision Variable:

The decision variable in our model is the quantity (in tons) used of each input raw material from glass waste cullet or pure raw material in order to produce the new product according to the standard of each product

3. Objective function:

The objective function defined as the total sum of the cost of each cullet glass type and pure materials according to their quantities. This objective is to be minimized

4. Constraints:

The set of constraints that taken into consideration are divided into: Output constraint, standard ratio of pure material in the total mix constraint to ensure that we have a final product within the international standards and the availability of local cullet glass at elite glass constraint

5. Formulation:

a. Notation

- n = be the total number of input recycled materials used in the final production
  - where i= 1,….,n and $i = (CFE, CFM, CBM, SiO2, Na2O, CaO \dots)$ as a **source** raw materials
- m = be the number of raw chemical material
  - where j=1,.., m and and $j = (SiO2, Na2O, CaO \dots)$ as **composition** raw materials
- q= be the number of capacities of available production lines
  - where h= 1….q and h= (40 tons/day, 200 tons/day)
- z = be the number of capacities of available production lines
  - where k= 1….z and k= (20 tons/day, 60 tons/day, 120 tons/day)
- Ci = be the cost (in $/tons) for each recycled and raw input materials

- Pji= Amount (%) of **composition** raw j (SiO2, Na2O, CaO…) in **source** material i (CFE-CFM – CBM - PureSiO2- pure Na2O…….)
- Uj = upper limit of raw material j (SiO2, Na2O, CaO…)
- Lj = lower limit of raw material j (SiO2, Na2O, CaO…)
- BCa_k = Capacities of available Bottle production line
- FCa_h = Capacities of available Flat production line

Decision Variable:

Xi = be the quantity (in tons) used of each input raw material

To clarify the variables more :

		Source Material (i)													
		CFE	CFM	CBM	SiO2	Na2O	Cao	Mgo	Al2O3	Fe2O3	K2O	So3	Cr2O3	objective Final Product (Flat or bottle)	
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	Li	Ui
Composition raw material (j)	SiO2	72.58%	72.08%	70.85%	100%	0%	0%	0%	0%	0%	0%	0%	0%	Mention in the tables (Percentage (%) of chemical raw materials found in standard Flat (& Solar) glass , and bottle glass)	
	Na2O	13.16%	7.06%	14.07%	0%	100%	0%	0%	0%	0%	0%	0%	0%		
	Cao	9.63%	8.92%	5.53%	0%	0%	100%	0%	0%	0%	0%	0%	0%		
	Mgo	3.10%	4.03%	5.53%	0%	0%	0%	100%	0%	0%	0%	0%	0%		
	Al2O3	1.53%	0.76%	4.02%	0%	0%	0%	0%	100%	0%	0%	0%	0%		
	Fe2O3	0.00%	0.10%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%		
	K2O	0.00%	7.06%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%		
	So3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%		
	Cr2O3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%		
	Cost $ /ton (Ci)	$0	$60	$60	$2,600	$1,000	$500	$2,000	$2,000	$800	$9,585,000	$3,625,000	$93,257		

Table 11:Input data for LP model

Where

i is the columns (the source raw material)

j is the column (composition raw material of each source)

Pji is the composition percentages in the table

Ci is the cost of each source if used

b. <u>Objective Function</u>

Objective Function is to minimize the total recycled cost plus the total cost of the added raw materials. The objective is written as:

$$\sum_{i}^{n} C_i X_i \qquad \text{(min)}$$

c. Constraint:

i. Output Constraint:

The output is the full capacity (because as the machine seller advice, the output must be as the capacity)

$$X_{CFE} + X_{CFM} + X_{CBM} + X_{SiO2} + \cdots = capacity$$

For Flat Glass : $\sum_i^n X_i \quad == \quad FCa_h$

For Bottle Glass : $\sum_i^n X_i \quad == \quad BCa_k$

ii. Standard ratio constraints:

The ratio of raw material j to the quantity of the produced (percentage of raw material j in the final product) must be between the standard boundaries of the final products

Let consider the chemical raw material, SiO. This product must meet the standard in the final mix in the final production of Bottle as output. The ratio of SiO2 must be between 66% and 88 % of the final output. Let us consider a mix of one ton of the final product of Bottle.

Given the data:

Amount of SiO2 in Elite Flat Cullet (CFE) = 72.6%

Amount of SiO2 in Market Flat Cullet (CFM) = 72%

Amount of SiO2 in Market Bottle Cullet (CBM) = 70.8%

Amount of SiO2 in SiO2 pure material = 100%

Amount of SiO2 in another (Na2O,CaO…) pure material = 0%

Since we are mixing XF and XB cullets, with other materials, then the percentage amount of SiO2 in the mix is expressed as follows:

$$0.66 \leq \frac{[0.726*X_{CFE}+0.72*X_{CFM}+0.708*X_{CBM}+1*X_{SiO2}+0*X_{Na2O}.....]}{[X_{CFE}+X_{CFM}+X_{CBM}+X_{SiO2}+X_{Na2O}+...]} \leq 0.88$$

Which become

$$\frac{\sum_i^n P_{ji}\,X_i}{\sum_i^n\,X_i} \geq L_j$$

$$\frac{\sum_i^n P_{ji}\,X_i}{\sum_i^n\,X_i} \leq U_j$$

iii. Availability of cullet glass waste at Elite Glass Company constraints:

Elite Glass company has approximately around 500 Kg of glass waste/day from their daily operation , so the quantity available for recycling is 0.5tons/day

$$X_{CFE} == 0.5$$

C. Net Present Value

The net present value (NPV) is used to calculate the difference between the present value of cash inflows and outflows over a period of time which is 10 years in our case. Here we used the net present value to analyze the profitability of each alternative investment and to know which alternative will be feasible in our case according to the capital budgeting and input variables which will determine the net cash flow that used in the NPV calculation

1. ***Input Variables***

- Demand at year 1 (in tons) for each product
- Annual Demand growth percentage (%)
- Depreciation rate of the fixed cost at year 1 (initial Investment) (%)
- Monetary values ($/unit) at year 1 including:
    - Unit price : price of each product in $ /ton
    - Variable cost : it is the sum of cost in $/ton for raw material, electricity ,gas, water and wages
- maintenance cost ($) : cost of maintenance of each machine per ton of the final product
- Inflation rate (%) : the rate of increase in prices
- Tax rate : the value of tax on the companies
- Discount Rate (%)

Decision variable:

Capacity that must be produced (in tons): As a start we consider 3000 tons in first year which is the available glass waste in elite glass landfill.

2. ***NPV calculation***

The input variable are used to determine the net cash flow that used with the discount rate to determine NPV

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Where:

Rt=net cash flow (cash inflow-outflows) during a single period of time t i=discount rate (return that could be earned in alternative)

t=number of time periods

3. Break even capacity

It's the least capacity where net present value is equal to zero so that the company can operate without gain or lose. This value is important to know because the company is new to the recycling industry where there can be uncertainty in logistics with the market so we can operate at the least capacity without losing. The minimum the capacity the better the choice.

It can be calculated using the Goal Seek option in the Excel's what if analysis

4. Sensitivity Analysis:

We run this analysis in order to know the variation of NPV according to the variation of chosen input at all given capacities for each alternative.

In this study we will make the analysis for the NPV according to the :

- Same given inputs for all capacities where breakeven capacity is determined
- With variation of demand growth
- With variation of discount rate
- With variation of tax rate

CHAPTER IV

RESULTS AND DISCUSSION

A. Model Results

After applying the LP model for getting the minimum cost for each product (flat or bottle) under set of technical constraints the results are shown below:

1. Flat Glass

	Flat Composition (tons)	
Input materials	**Capacity: 40tons/day**	**Capacity: 200 tons/day**
x[CFE]	0.5	0.5
x[CFM]	0	0
x[CBM]	29.89	150.21
x[SiO2]	5.87	30.28
x[Na2O]	0	0
x[Cao]	3.7	19
x[Mgo]	0	0
x[Al2O3]	0	0
x[Cr2O3]	0	0
x[Fe2O3]	0	0
x[K2O]	0	0
x[SO3]	0	0
COST ($)	**18930.7**	**97264.336**

Table 12: Flat glass composition result

2. Bottle Glass

Bottle Composition (tons)			
Input material	**Capacity: 20tons/day**	**Capacity: 60 tons/day**	**Capacity: 120 tons/day**
x[CFE]	0.5	0.5	0.5
x[CFM]	11.33	34.01	68.02
x[CBM]	8.16	25.48	51.47
x[SiO2]	0	0	0
x[Na2O]	0	0	0
x[Cao]	0	0	0
x[Mgo]	0	0	0
x[Al2O3]	0	0	0
x[Cr2O3]	0	0	0
x[Fe2O3]	0	0	0
x[K2O]	0	0	0
x[SO3]	0	0	0
COST ($)	**1170**	**3570**	**7170**

Table 13:Bottle glass composition results

3. Findings

a- The Elite Glass waste cullet is fully used (0.5 tons/day) which means that if a convention done with other flat glass in Lebanon or region that use the same type of glass or approximately same composition this will decrease sharply the cost

b- It's clear that no amount was taken from Market flat cullet glass (CFM) for flat glass product, that's because

i- The composition of CFM is different from our flat product standard ii- This study takes these of composition of cullet from international website where waste cullet composition is estimated for the aim of study the concept of recycling. Because there is a lack of data in Lebanon no estimation for cullet was found. Market flat glass (CFM) was taken from WRAP protocol that estimate the composition for UK factories.

c- This cullet is not always used because each cullet amount will be of different composition so for each daily process the composition of cullet must be determined to determine how much quantities should be added.

B. Net Present Value

Before going further in the results let us define the following alternatives machines names for the ease of using it in the report:

- Flat 1 (40 tons /day)
- Flat2 (200 tons/day)
- Bottle1 (20 tons /day)
- Bottle2 (60 tons/day)
- Bottle3 (120 tons/day)
- Flat1+Solar1 (40 tons/day : 34.05 for flat selling and 5.05 for solar panel glass)
- Flat1+Solar2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass)
- Flat1+Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass)
- Flat2+Solar1 (200 tons/day : 194.05 for flat selling and 5.05 for solar panel glass)
- Flat2+Solar2 (200 tons/day : 188.4 for flat selling and 11.6 for solar panel glass)

- Flat2+Solar 3 (200 tons/day : 183.3 for flat selling and 16.7 for solar panel glass)

1. ***Input variables results***

a. Demand at year 1 (in tons) : [26]

Alternatives	Market Demand (tons/year)
Flat Glass	74202
Bottle Glass	89600
Solar Panel Glass	513281

Table 14: Market demand of final products

b. Annual Demand growth percentage (%):

- for flat its around 10% for the first 4 years because of the renovation after Beirut explosion and then the construction industry returns stable [27]
- for bottle its around 3% for first 4 years because of the need of bottle glass due to the change from plastic to bottle in several industries [28] and then mature
- for solar its around 30% for first 4 years and then 50% for the remaining years assuming the situation in Lebanon will be stable and the government plan of solar electricity production applied [29]

c. Depreciation rate of the fixed cost at year 1 (initial Investment) (%):

- Each alternative has its own initial investment
- Depreciation will be 10% over 10 years

	Area(m2)	land cost($)	Building Cost($)	Machine Cost ($)		Initial Investemnt ($)	Yearly Depreciation($)
Flat 1	2700	135000	270000	3022961		3427961	342796.1
Flat 2	66000	9630000	6600000	14667741		30897741	3089774.1
Bottle 1	1800	270000	180000	2326121		2776121	277612.1
Bottle 2	5000	480000	500000	3944351		4924351	492435.1
Bottle 3	9500	1155000	950000	4907131		7012131	701213.1
Flat1+ Solar 1	3600	270000	360000	3410061		4040061	404006.1
Flat 1+ Solar2	3800	300000	380000	3663961		4343961	434396.1
Flat 1+ Solar3	4050	337500	405000	3962761		4705261	470526.1
Flat2+ Solar 1	66900	9765000	6690000	15054841		31509841	3150984.1
Flat 2+ Solar2	67100	9795000	6710000	15308741		31813741	3181374.1
Flat 2+ Solar3	67350	9832500	6735000	15607541		32175041	3217504.1

Table 15:Yearly Depreciation of Initial Investments

d. Monetary values ($/unit) at year 1 including :

i. Unit price : price of each product in $ /ton

- Flat Glass:

  Each glass ton produce around 40 m2 of glass

  where each 1 m2 sold at 13$

  Revenue/ton = 13$*40m2 = 520$/ton

- Bottle Glass:

  Each glass ton produce around 4270 pieces of glass bottle

  where each bottle glass is sold at 0.16 $

  Revenue/ton = 0.16$*4270 pieces = 683.2 $/ton

- Solar Panel:

  Each glass ton produce around 62 panel of standard specification of 320 W and 60 cells

  where each solar panel sold at 83 $

  Revenue/ton = 83$*62 panels = 5146 $/ton

ii. Variable cost: it is the sum of cost in $/ton for raw material, electricity ,gas, water and wages

- Raw material cost $/ton:

  From the above chapter we determine the cost of raw material for the daily capacity of each alternative, by dividing these values by the capacity of each alternative we can find the cost$/ton

  For example: the raw material cost of 20 tons/day is 1170 $

  Cost $/ton = 1170/20 = 58.5$/ton

  Full results are shown in the table below:

FINAL Values	Capacity tons/day	Raw cost of full capacity ($)	Raw cost $ /ton
Flat 1	40	18930.7	473.2675
Flat 2	200	97264.336	486.32168
Bottle 1	20	1170	58.5
Bottle 2	60	3570	59.5
Bottle 3	120	7170	59.75
Flat1+ Solar 1	40	18930.7	473.2675
Flat 1+ Solar2	40	18930.7	473.2675
Flat 1+ Solar3	40	18930.7	473.2675
Flat2+ Solar 1	200	97264.336	486.32168
Flat 2+ Solar2	200	97264.336	486.32168
Flat 2+ Solar3	200	97264.336	486.32168

Table 16:Raw material cost for each alternative

- Electricity cost ($/ton):
  - We have two parts for electricity consumptions,
    - Furnace electricity consumption which runs always for 365 day/year
    - Remaining production line which runs for 300 days /year
  - The electricity cost is 0.03$/KW [30]

- Calculation:
  - Total electricity consumption KW /year was calculated using the following formula:

$$365 \text{ days x Electricity of furnace} \left(\frac{\text{KW}}{\text{day}}\right) + 300 \text{ days x Electricity of production line} \left(\frac{\text{KW}}{\text{day}}\right)$$

  - Electricity cost $/ton was calculated using the following formula:

$$\frac{\left(0.03 \left(\frac{\$}{\text{KW}}\right) \text{ x Total electricity consumption } \left(\frac{\text{KW}}{\text{year}}\right)\right)}{\text{Capacity } \left(\frac{\text{tons}}{\text{year}}\right)}$$

  - For example: take Bottle (20 tons/day)

Total electricity consumption $\left(\frac{\text{KW}}{\text{year}}\right)$ = 365 x 980.84+300 x 3923.36

= 2535014.6 KW/year

Electricity cost ($/ton) = 0.03 x 2535014.6 /6000 = **7.675 $/ton**

Alternatives	Capacity/day	Capacity /year	Electricity of Furnace (KW/day)	Electricty of production line (except furnace) (KW/day)	Total Electricity KW/year	Total Electricity $/ton
Flat 1	40	12000	12035.04	48140.16	18834837.6	47.087094
Flat 2	200	60000	34708.64	138834.56	54319021.6	27.1595108
Bottle 1	20	6000	980.84	3923.36	1535014.6	7.675073
Bottle 2	60	18000	1729.24	6916.96	2706260.6	4.510434333
Bottle 3	120	36000	2971.84	11887.36	4650929.6	3.875774667
Flat1+ Solar 1	40	12000	12035.04	48940.16	19074837.6	47.687094
Flat 1+ Solar2	40	12000	12035.04	53660.16	20490837.6	51.227094
Flat 1+ Solar3	40	12000	12035.04	56060.16	21210837.6	53.027094
Flat2+ Solar 1	200	60000	34708.64	144354.56	55975021.6	27.9875108
Flat 2+ Solar2	200	60000	34708.64	146754.56	56695021.6	28.3475108
Flat 2+ Solar3	200	60000	34708.64	138834.56	54319021.6	27.1595108

Table 17: Electricity cost for each alternative

- Gas cost ($/ton):
  - Only flat and bottle glass machines have gas consumption

- The Gas cost is 0.2$/liter [31]
- Calculation:
  - Gas cost ($/day) was calculated using the following formula:

$$\text{Gas Consumption} \left(\frac{\text{liter}}{\text{day}}\right) \text{x } 0.2 \left(\frac{\$}{\text{liter}}\right)$$

  - Gas cost ($/ton) was calculated using the following formula:

$$\frac{\text{Gas cost} \left(\frac{\$}{\text{day}}\right)}{\text{Capacity} \left(\frac{\text{tons}}{\text{day}}\right)}$$

  - For example: take Bottle (20 tons/day)

Gas cost ($/day)= 13320 x 0.2 = 2664 $/day

Gas cost ($/ton) = 2664 /20 = **33.3 $/ton**

Alternatives	Capacity	Gas consumption (Liter/day)	Gas cost $ /day	cost Gas ($)/ton
Flat 1	40	29600	5920	37
Flat 2	200	133200	26640	33.3
Bottle 1	20	13320	2664	33.3
Bottle 2	60	37000	7400	30.83333333
Bottle 3	120	70300	14060	29.29166667
Flat1+ Solar 1	40	29600	5920	37
Flat 1+ Solar2	40	29600	5920	37
Flat 1+ Solar3	40	29600	5920	37
Flat2+ Solar 1	200	133200	26640	33.3
Flat 2+ Solar2	200	133200	26640	33.3
Flat 2+ Solar3	200	133200	26640	33.3

Table 18:Gas cost for each alternative

- Water Costs:
  - Only flat and bottle glass machines have water consumption
  - The water cost is 0.25 $/ton [32]
  - Calculation:
    - Water cost ($/day) was calculated using the following formula:

$$\text{Water Consumption } \left(\frac{\text{liter}}{\text{day}}\right) \text{x } 0.25 \left(\frac{\$}{\text{liter}}\right)$$

- Water cost ($/ton) was calculated using the following formula:

$$\frac{\text{water cost } \left(\frac{\$}{\text{day}}\right)}{\text{Capacity } \left(\frac{\text{tons}}{\text{day}}\right)}$$

- For example: take Bottle (20 tons/day)

Water cost($/day)= 200 x 0.25 = **50 $/day**

Water cost ($/ton) = 50/20 = **2.5 $/ton**

Alternatives	Capacity (tons/day)	Water consumption (tons /day)	water cost ($)/day	water cost ($)/ton
Flat 1	40	250	62.5	1.5625
Flat 2	200	900	225	1.125
Bottle 1	20	200	50	2.5
Bottle 2	60	500	125	2.083333333
Bottle 3	120	850	212.5	1.770833333
Flat1+ Solar 1	40	250	62.5	1.5625
Flat 1+ Solar2	40	250	62.5	1.5625
Flat 1+ Solar3	40	250	62.5	1.5625
Flat2+ Solar 1	200	900	225	1.125
Flat 2+ Solar2	200	900	225	1.125
Flat 2+ Solar3	200	900	225	1.125

Table 19:Water cost for each alternative

- Wages cost:
  - Worker wage per month is 500$
  - Calculation:
    - Total wages cost per month =

$$\text{Workers needed x } 500\ \$$$

- Wages cost($/ ton) =

$$\frac{\text{Total wages cost } \left(\frac{\$}{\text{month}}\right)}{\text{Capacity } \left(\frac{\text{tons}}{\text{month}}\right)}$$

Alternatives	Capacity (tons/day)	Capacity (tons/month)	workers needed	Total wages Cost($/month)	wages ($/ton)
Flat 1	40	1000	50	25000	25
Flat 2	200	5000	230	115000	23
Bottle 1	20	500	35	17500	35
Bottle 2	60	1500	115	57500	38.33333333
Bottle 3	120	3000	200	100000	33.33333333
Flat1+ Solar 1	40	1000	62	31000	31
Flat 1+ Solar2	40	1000	104	52000	52
Flat 1+ Solar3	40	1000	112	56000	56
Flat2+ Solar 1	200	5000	242	121000	24.2
Flat 2+ Solar2	200	5000	284	142000	28.4
Flat 2+ Solar3	200	5000	296	148000	29.6

Table 20: Wages cost for each alternative

- Solar Cell cost:
  - o Each solar panel need 60 cells
  - o Cost of one solar cell is 0.13 $
  - o Calculation:

    Solar cell cost per ton =

    0.13$/cell x 60 cells/panel x nb of solar panel per ton

    = 0.13($/cell) x 60 (cell /panel) x 62 (panel/ton)

    = 483.6 $ /ton

- Aluminum Frame Cost:
  - o Each solar panel need 0.5 kg of aluminum frame
  - o Cost of one kg of aluminum frame is 2.95 $
  - o Calculation:

    Aluminum frame cost per ton =

    2.95$/kg x 0.5 kg/panel x nb of solar panel per ton

    = 2.95($/kg) x 0.5 (kg/panel) x 62 (panel/ton)

    = 91.45 $ /ton

The full results for unit variable cost are shown in the table below:

		Variable Cost ($/ton)							
Alternatives	Capacity tons/day	Raw Material Cost	Electricity Cost	Gas Cost	Wages Cost	Water Cost	Solar Cells cost	Aluminum Frame cost	Unit Cost
Flat 1	40	473.3	47.1	37.0	25.0	1.6			584
Flat 2	200	486.3	27.2	33.3	23.0	1.1			571
Bottle 1	20	58.5	7.7	33.3	35.0	2.5			137
Bottle 2	60	59.5	4.5	30.8	38.3	2.1			135
Bottle 3	120	59.8	3.9	29.3	33.3	1.8			128
Flat1+ Solar 1	40	473.3	47.7	37.0	31.0	1.6	483.6	91.5	1166
Flat 1+ Solar2	40	473.3	51.2	37.0	52.0	1.6	483.6	91.5	1190
Flat 1+ Solar3	40	473.3	53.0	37.0	56.0	1.6	483.6	91.5	1196
Flat2+ Solar 1	200	486.3	28.0	33.3	24.2	1.1	483.6	91.5	1148
Flat 2+ Solar2	200	486.3	28.3	33.3	28.4	1.1	483.6	91.5	1153
Flat 2+ Solar3	200	486.3	27.2	33.3	29.6	1.1	483.6	91.5	1153

Table 21:Total variable cost for each alternative

iii. Maintenance cost ($): cost of maintenance of each machine per ton of the final product

Its calculated yearly as 2% of the machine cost

Alternatives	**Yearly maintance ($)**	**Capacity (tons/year)**	**Mainatnce ($ /ton)**
Flat 1	60459.22	12000	5
Flat 2	293354.82	60000	5
Bottle 1	46522.42	6000	8
Bottle 2	78887.02	18000	4
Bottle 3	98142.62	36000	3
Flat1+ Solar 1	68201.22	12000	6
Flat 1+ Solar2	73279.22	12000	6
Flat 1+ Solar3	79255.22	12000	7
Flat2+ Solar 1	301096.82	60000	5
Flat 2+ Solar2	306174.82	60000	5
Flat 2+ Solar3	312150.82	60000	5

Table 22:Maintenance cost for each alternative

e. Inflation rate (%):

The inflation rate in Lebanon is considered as average of 3% [33]

f. Tax rate (%)

The first three years after starting the business will be waved from tax , after that a tax of 17% will be applied on year 4 and after [34]

g. Discount rate(%):

We took a discount rate of average 10% per year [35]

h. Decision variable:

Capacity (tons/year): As a start we consider 3000 tons in first year which is the available glass waste in elite glass landfill

2. ***Sensitivity Analysis***

Sensitivity analysis for the elven alternatives were done where the variation of net present value was studied as a function of capacities, demand, discount rate, and tax rate.

In this part the following five machines will be discussed :

- Bottle 1 (20 tons/day)
- Bottle 2 (60 tons/day)
- Bottle 3 (120 tons/day)
- Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass)
- Flat1+ Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass)

And that because other six alternatives were always of negative NPV regardless any comparison or variation with the other inputs (capacities, demand, discount rate, and tax rate) which mainly because their unit cost alone is greater than their unit price, this difference will increase also with the addition of maintenance and depreciation cost.

The table below shows this gap:

Alternatives	Capacity tons/day	unit price ($/ton)	Unit cost $/ton	Unit Maintanace Cost $/ton	Initial Investemnt $
Flat 1	40	$520	$584	$5	$3,427,961
Flat 2	200	$520	$571	$5	$30,897,741
Bottle 1	20	$683	$137	$8	$2,776,121
Bottle 2	60	$683	$135	$4	$4,924,351
Bottle 3	120	$683	$128	$3	$7,012,131
Flat1+ Solar 1	40	$1,104	$1,166	$6	$4,040,061
Flat 1+ Solar2	40	$1,862	$1,190	$6	$4,343,961
Flat 1+ Solar3	40	$2,451	$1,196	$7	$4,705,261
Flat2+ Solar 1	200	$637	$1,148	$5	$31,509,841
Flat 2+ Solar2	200	$788	$1,153	$5	$31,813,741
Flat 2+ Solar3	200	$906	$1,153	$5	$32,175,041

Table 23:Full data (revenues and costs) for each alternative

a. <u>NPV with Capacities:</u>

A sensitivity analysis done to see the variation of NPV with respect to the change in capacity of each alternative

The capacities included in all analysis are starting from 150 tons/year as a minimum quantity which is the amount of yearly Elite glass company's waste cullet. Then we used 5 % of the full capacity as the second capacity point, then we increase by 5% on each point (10%,15%,20%, …..) till the full capacity according to the capacity of each alternative.

In this part, the breakeven capacity where NPV will be zero will be determined also.

- Bottle 1 (20 tons/day, 6000 tons/year)

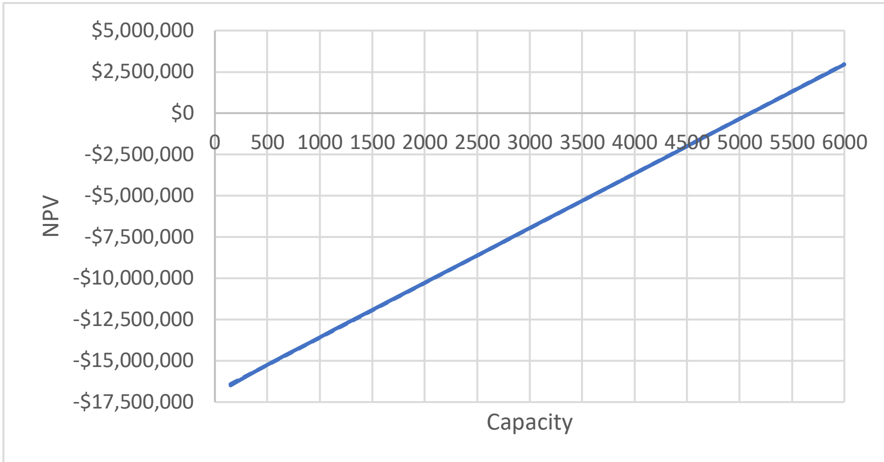

Figure 11:Graph showing the variation of NPV vs. Capacity for Bottle 1

The graph shows that NPV is increasing with the increase in capacity, but the alternative will not be profitable except at capacities greater than 5,105 tons/year , which means that this production line can be operate except at 85 % or greater of its full capacity.

The maximum NPV $2,961,161 will be reached at full capacity of 6000 tons/year

- Bottle 2 (60 tons/day, 18000 tons/year)

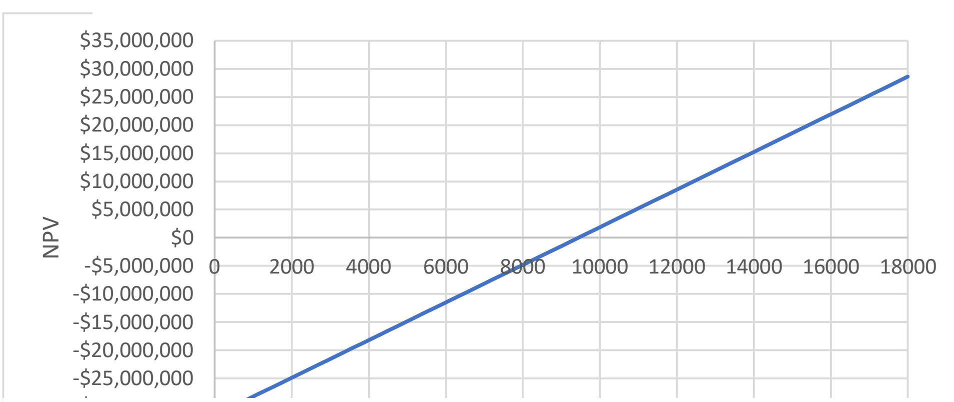

Figure 12:Graph showing the variation of NPV vs. Capacity for Bottle 2

The graph shows that NPV is increasing with the increase in capacity, but the alternative will not be profitable except at capacities greater than 9446 tons/year , which means that this production line can be operate except at 52% or greater of its full capacity.

The maximum NPV $28,609,767 will be reached at full capacity of 18000 tons/year

- Bottle 3 (120 tons/day, 36000 tons/year

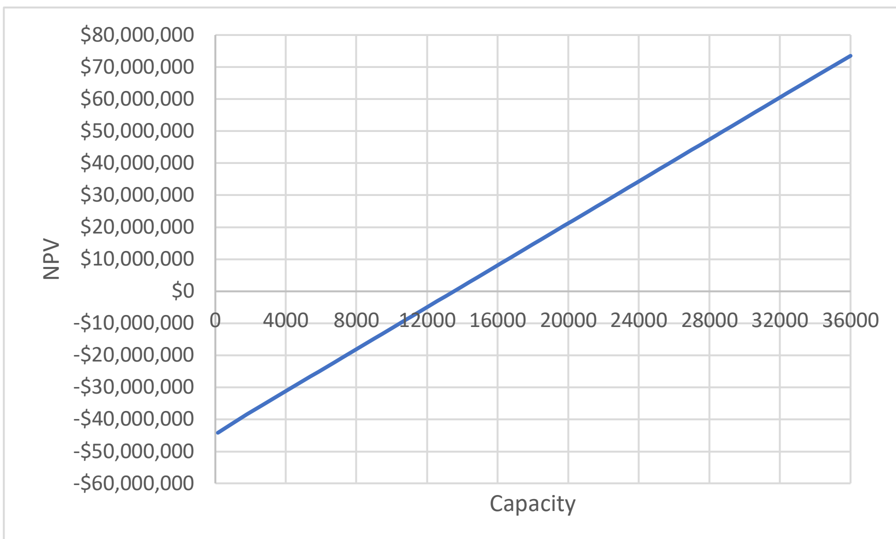

Figure 13:Graph showing the variation of NPV vs. Capacity for Bottle 3

The graph shows that NPV is increasing with the increase in capacity, but the alternative will not be profitable except at capacities greater than 13532 tons/year , which means that this production line can be operate except at 37.5% or greater of its full capacity.

The maximum NPV $73,543,120 will be reached at full capacity of 36000 tons/year

- Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass, 12000 tons/year)

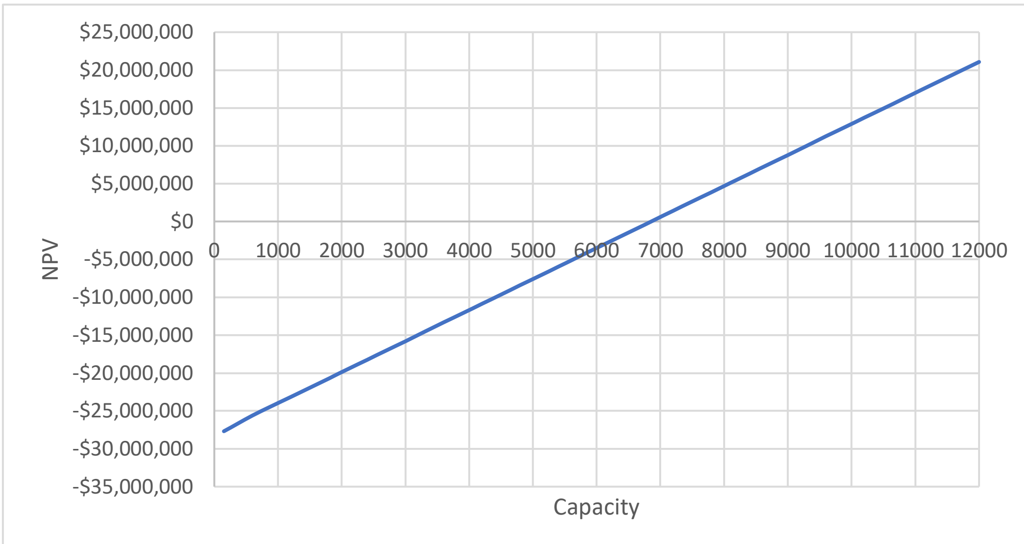

Figure 14:Graph showing the variation of NPV vs. Capacity for (Flat1 + Solar2)

The graph shows that NPV is increasing with the increase in capacity, but the alternative will not be profitable except at capacities greater than 6854 tons/year , which means that this production line can be operate except at 57% or greater of its full capacity.

The maximum NPV $21,073,045 will be reached at full capacity of 12000 tons/year

- Flat1+ Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass,12000 tons/year)

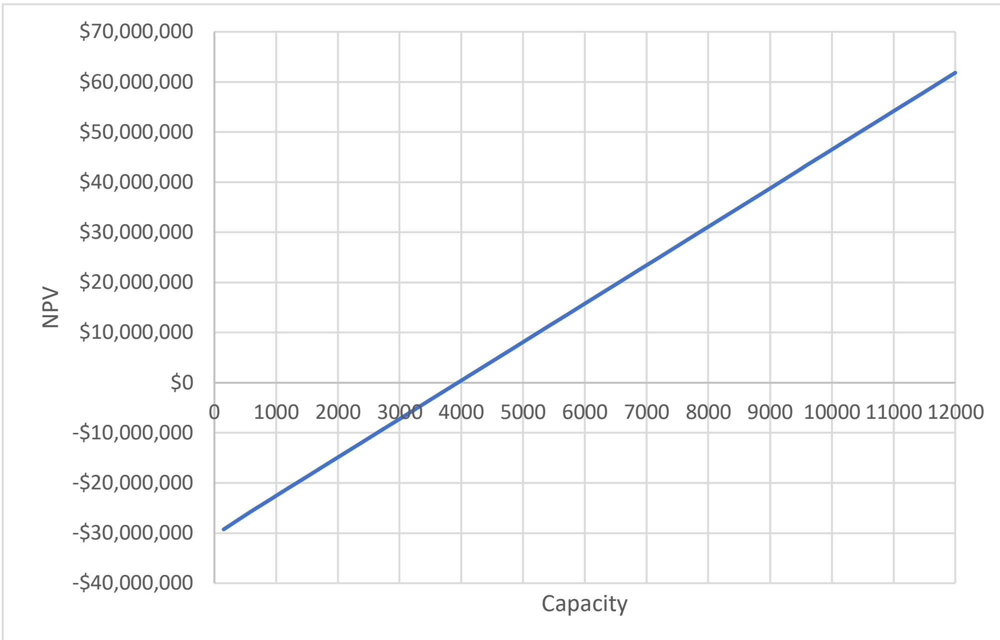

Figure 15:Graph showing the variation of NPV vs. Capacity for (Flat 1+Solar 3)

The graph shows that NPV is increasing with the increase in capacity, but the alternative will not be profitable except at capacities greater than 3944 tons/year , which means that this production line can be operate except at 33% or greater of its full capacity.

The maximum NPV $61,814,964 will be reached at full capacity of 12000 tons/year

b. <u>Demand:</u>

As mentioned in Table 9 the yearly demand is always higher than the maximum capacity of the alternatives, so the growth in the demand will not affect NPV

The graph below shows that NPV is the same across all demands growth, it acts as one line, and the breakeven capacity and the capacity corresponding to the maximum NPV are still the same

These results are shown in the tables below

- Bottle1 (20 tons/day, 6000 tons/year)

Demand Growth	1%	2%	3%	4%	5%	6%
Maximum NPV	$2,961,161	$2,961,161	$2,961,161	$2,961,161	$2,961,161	$2,961,161
Corresponding capacity	6000	6000	6000	6000	6000	6000
%difference in NPV	0	0	0	0	0	0

Table 24:Variation of NPV as a function of demand growth for Bottle 1 (20 ton/day)

- Bottle2 (60tons/day,18000 tons/year)

Demand growth	1%	2%	3%	4%	5%	6%
Maximum NPV	$28,609,767	$28,609,767	$28,609,767	$28,609,767	$28,609,767	$28,609,767
Corresponding capacity	18000	18000	18000	18000	18000	18000
%difference in NPV	0	0	0	0	0	0

Table 25:Variation of NPV as a function of demand growth for Bottle 2 (60 ton/day)

- Bottle3 (120 tons/day , 36000 tons/year)

Demand Growth	1%	2%	3%	4%	5%	6%
Maximum NPV	$73,543,120	$73,543,120	$73,543,120	$73,543,120	$73,543,120	$73,543,120
Corresponding capacity	36000	36000	36000	36000	36000	36000
%difference in NPV	0	0	0	0	0	0

Table 26:Variation of NPV as a function of demand growth for Bottle 3 (120 ton/day)

- Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass, 12000 tons/year)

Demand Growth	1%	2%	3%	4%	5%	6%
Maximum NPV	$21,073,045	$21,073,045	$21,073,045	$21,073,045	$21,073,045	$21,073,045
Corresponding capacity	12000	12000	12000	12000	12000	12000
%difference in NPV	0	0	0	0	0	0

Table 27:Variation of NPV as a function of demand growth for Flat1+Solar2 (40 tons/day: 28.4 for flat selling and 11.6 for solar panel glass)

- Flat1+ Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass,12000 tons/year)

Demand Growth	1%	2%	3%	4%	5%	6%
Maximum NPV	$61,814,964	$61,814,964	$61,814,964	$61,814,964	$61,814,964	$61,814,964
Corresponding capacity	12000	12000	12000	12000	12000	12000
%difference in NPV	0	0	0	0	0	0

Table 28:Variation of NPV as a function of demand growth for Flat1+Solar3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass)

c. Discount Rate:

We used 10% as our discount rate, the analysis showed that with each 1% increase of discount rate, NPV will decrease by 4 to 5% approximately which means that if we get a lower discount rate we can achieve more profits

- Bottle1 (20 tons/day, 6000 tons/year)

Discount rate	5%	6%	7%	8%	9%	10%
Maximum NPV	$3,774,549	$3,586,335	$3,412,078	$3,250,526	$3,100,557	$2,961,161
Corresponding capacity	6000	6000	6000	6000	6000	6000
%NPV difference		4.99%	4.86%	4.73%	4.61%	4.50%

Table 29:Variation of NPV as a function of discount rate for Bottle 1 (20 ton/day)

- Bottle2 (60tons/day,18000 tons/year)

Discount rate	5%	6%	7%	8%	9%	10%
Maximum NPV	$36,092,945	$34,372,091	$32,773,409	$31,286,325	$29,901,311	$28,609,767
Corresponding capacity	18000	18000	18000	18000	18000	18000
%NPV difference		4.77%	4.65%	4.54%	4.43%	4.32%

Table 30:Variation of NPV as a function of discount rate for Bottle 2 (60 ton/day)

- Bottle3 (120 tons/day , 36000 tons/year)

Discount rate	5%	6%	7%	8%	9%	10%
Maximum NPV	$92,118,476	$87,857,562	$83,893,766	$80,201,672	$76,758,359	$73,543,120
Corresponding capacity	36000	36000	36000	36000	36000	36000
%NPV difference		4.63%	4.51%	4.40%	4.29%	4.19%

Table 31:Variation of NPV as a function of discount rate for Bottle 3 (120 tons/day)

- Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass, 12000 tons/year)

Discount rate	5%	6%	7%	8%	9%	10%
Maximum NPV	$26,598,597	$25,327,515	$24,146,882	$23,048,855	$22,026,368	$21,073,045
Corresponding capacity	12000	12000	12000	12000	12000	12000
%NPV difference		4.78%	4.66%	4.55%	4.44%	4.33%

Table 32:Variation of NPV as a function of discount rate for Flat1+Solar2 (40 tons/day: 28.4 for flat selling and 11.6 for solar panel glass)

- Flat1+ Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass,12000 tons/year)

Discount rate	5%	6%	7%	8%	9%	10%
Maximum NPV	$77,874,826	$74,184,903	$70,755,288	$67,563,570	$64,589,543	$61,814,964
Corresponding capacity	12000	12000	12000	12000	12000	12000
%NPV difference		4.74%	4.62%	4.51%	4.40%	4.30%

Table 33:Variation of NPV as a function of discount rate for Flat1+Solar3 (40 tons/day: 23.3for flat selling and 16.7 for solar panel glass)

d. <u>Tax rate:</u>

The taxes in Lebanon is 17%, the analysis showed that with the increase of taxes, NPV decreases 2.5% to 3.5% in Bottle 1 (20 ton/day) while 1% to 2% decrease in the rest which means that the tax rate affect the smaller projects more and if the government decrease the tax or waved it for more than 3 years the company will achieve higher profits

- Bottle1 (20 tons/day, 6000 tons/year)

Tax rate	1.00%	3.00%	5.00%	7.00%	9.00%	10.00%	11.00%	13.00%	15.00%	17.00%
Maximum NPV	5033162.757	4774162.557	4515162.357	4256162.157	3997161.957	3867661.857	3738161.757	3479161.557	3220161.356	2961161.156
Corresponding capacity	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
% NPV difference		-5.15%	-5.43%	-5.74%	-6.09%	-3.24%	-3.35%	-6.93%	-7.44%	-8.04%

Table 34:Variation of NPV as a function of tax rate for Bottle 1 (20 ton/day)

- Bottle2 (60tons/day,18000 tons/year)

Tax rate	1.00%	3.00%	5.00%	7.00%	9.00%	10.00%	11.00%	13.00%	15.00%	17.00%
Maximum NPV	35083943.86	34274671.71	33465399.57	32656127.42	31846855.27	31442219.2	31037583.12	30228310.97	29419038.83	28609766.68
Corresponding capacity	18000	18000	18000	18000	18000	18000	18000	18000	18000	18000
% NPV difference		-2.31%	-2.36%	-2.42%	-2.48%	-1.27%	-1.29%	-2.61%	-2.68%	-2.75%

Table 35:Variation of NPV as a function of tax rate for Bottle 2 (60 ton/day)

- Bottle3 (120 tons/day , 36000 tons/year)

Tax rate	1.00%	3.00%	5.00%	7.00%	9.00%	10.00%	11.00%	13.00%	15.00%	17.00%
Maximum NPV	86126195.75	84553311.31	82980426.88	81407542.44	79834658.01	79048215.79	78261773.57	76688889.14	75116004.7	73543120.27
Corresponding capacity	36000	36000	36000	36000	36000	36000	36000	36000	36000	36000
% NPV difference		-1.83%	-1.86%	-1.90%	-1.93%	-0.99%	-0.99%	-2.01%	-2.05%	-2.09%

Table 36:Variation of NPV as a function of tax rate for Bottle 3 (120 ton/day)

- Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass, 12000 tons/year)

Tax rate	1.00%	3.00%	5.00%	7.00%	9.00%	10.00%	11.00%	13.00%	15.00%	17.00%
Maximum NPV	26335201.8	25677432.2	25019662.61	24361893.01	23704123.42	23375238.62	23046353.83	22388584.23	21730814.64	21073045.05
Corresponding capacity	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
% NPV difference		-2.50%	-2.56%	-2.63%	-2.70%	-1.39%	-1.41%	-2.85%	-2.94%	-3.03%

Table 37:Variation of NPV as a function of tax rate for Flat1+ Solar 2 (40 tons/day : 28.4 for flat selling and 11.6 for solar panel glass, 12000 tons/year)

- Flat1+ Solar 3 (40 tons/day : 23.3 for flat selling and 16.7 for solar panel glass,12000 tons/year)

Tax rate	1.00%	3.00%	5.00%	7.00%	9.00%	10.00%	11.00%	13.00%	15.00%	17.00%
Maximum NPV	71890405.36	70630975.21	69371545.06	68112114.9	66852684.75	65593254.6	64333824.45	63074394.29	61814964.14	60555533.99
Corresponding capacity	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
% NPV difference		-1.75%	-1.78%	-1.82%	-1.85%	-1.88%	-1.92%	-1.96%	-2.00%	-2.04%

Table 38:Variation of NPV as a function of tax rate for Flat1+Solar3 (40 tons/day: 23.3for flat selling and 16.7 for solar panel glass)

e. <u>Findings:</u>

- Maximum NPV achieved at full capacities
- The project is not affected with the demand growth, any capacity can be good

- The lower the discount rate the best, so the project can achieve higher NPV or need lower capacities to achieve positive NPV
- The lower the tax rate the best, so the project can achieve higher NPV or need lower capacities to achieve positive NPV
- All given projects are profitable projects, the higher NPV the better but in our case we have several constraints that we must take into account:
    - The ability to have the initial Investment costs that needed at year 1
    - Availability of land area needed for the project
    - Ability to provide at least the breakeven capacity of the project so the company can operate at least without losses especially in the first 2 years where logistics process can take time to going to market for using the full capacity

The data of the given constraints are in the table below:

Alternatives	Capacity (tons/day)	Capacity (tons/year)	NPV (Full capacity) ($)	Break Even Capacity (tons)	Area (m2)	Initial Investemnt ($)
Bottle 1	20	6000	$2,961,161	5,105	1800	$2,776,121
Bottle 2	60	18000	$28,609,767	9,446	5000	$4,924,351
Bottle 3	120	36000	$73,543,120	13,532	9500	$7,012,131
Flat1+ Solar 2	40	12000	$21,073,045	6854	3800	$4,343,961
Flat1+ Solar 3	40	12000	$61,814,964	3944	4050	$4,705,261

Table 39:Constraints that affect the choosing of the best fit project

- The production line of Bottle2 (60 tons/day) and Bottle3 (120tons/day) have a very high NPV but their corresponding Breakeven capacity, area and initial investment are very high also, so they are recommended for a big manufacturer
- The two solar production alternatives are recommended for intermediate manufacturer where they have lower breakeven capacity, area and initial investment

- The Bottle 1 (20 tons/day) production line are recommended for a small startup company where it has a low NPV but it does not need a large area or initial investment

For the case of Elite glass factory, it is an middle size company where its choices range between small and intermediate projects.

- The advantage of the fifth project (Flat1+Solar3) is that it has a low breakeven capacity and a very high NPV , so if Elite glass company can afford around 4000 m2 land and around 5,000,000 $ as initial investment then this project will be the best.
- For the fourth project (Flat1+ Solar2) , it does not have a very big difference from fifth one regarding the area and the initial investment , in addition to that it has a double breakeven capacity which means that its not a good choice.
- Bottle 1 production line is the best choice if elite glass cannot afford the costs and the needs of the fifth project (Flat1+Solar3), and decided to start with a low risk project

CHAPTER V

CONCLUSION

As a conclusion, for the aim of studying the feasibility of start a glass recycling manufacturing, an LP model was applied in this paper to determine the quantity usage of different waste cullet and pure material in the production of different final product (flat, bottle glass). Based on the results of the model we can conclude that:

- The new products composition is suitable with different types of cullet that can be mixed resulting in decreasing the usage of pure material and therefore decrease the cost.
- Elite glass waste cullet is suitable for all new final products composition which means that by lunching the project the glass waste of Elite glass and the factories that used the same type of glass will be used and removed from the landfills.
- Composition detection of each new quantity of market cullet must be done before introducing the cullet in the production process.

Then an NPV model was built taking into consideration external influences like demand growth, inflation rate, tax rate and internal influences like the initial investment, capacity, unit price and cost in order to determine the profitable projects. Based on the results of the NPV model five projects were chosen and ran undergo the sensitivity analysis which results in:

- Discount rate and Taxes have an inversely proportion relation with the NPV, so if government support and encourage these types for projects for the aim of recycling, this will results in more profitable projects

- Each of the five projects is of high NPV and profitable but each company can choose one of the alternatives according to its abilities and strength in the market.

For a small and low risk decision, Bottle1 (20 tons/day) will be the best choice for elite glass company while for more profitable project (Flat1+ Solar 3) project will be the best.

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