T.C.

İSTANBUL KÜLTÜR UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

IMPACT OF USING RECYCLED RAW MATERIAL ON SUSTAINABILITY AT A PACKAGING MANUFACTURER

MASTER OF SCIENCE THESIS

Omar ALJOUJA

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Department: Industrial Engineering

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Members of Examining Committee: **Assist. Prof. İbrahim Ethem TARHAN**

Assist. Prof. Batin Latif AYLAK

February 2024

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01 February 2024 Omar Aljouja

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Programı	: **Mühendislik Yönetimi**
Tez Danışmanı	: **Prof. Dr. Ayşe Tülin AKTİN**
Tez Türü ve Tarihi	: **Yüksek Lisans – Şubat 2024**

ÖZET

Bir Ambalaj Üreticisinde Geri Dönüştürülmüş Hammadde Kullanımının Sürdürülebilirlik Üzerindeki Etkisi

Omar Aljouja

Sürdürülebilirlik, dünya ekosisteminin çok önemli bir parçasıdır. Kaynakların gelecek nesiller için kullanılabilir olmasını sağlarken, iklim değişikliği olasılığını azaltır. Dünyadaki tüm karar vericiler için etik ve zorunlu bir sorumluluk olup, hesap verebilir kaynak kullanımını, ekonomik istikrarı ve sosyal eşitliği teşvik eder, insanlar ve doğa arasında uzun vadeli sağlık ve refah için gerekli olan bir dengeyi özendirir. Bu çalışma, ekonomik, çevresel ve sosyal sürdürülebilirlik sorularını içeren bir anketin hazırlanması ve farklı oranlarda geri dönüştürülebilir hammadde kullanan bir geri dönüştürülebilir ambalaj üreticisinde uygulanarak, bunun üç sürdürülebilirlik piramidi üzerindeki etkisinin ölçülmesiyle başlamıştır. Anket sonuçları Excel ve GAMS/CPLEX çözücüsü kullanılarak toplanmış ve analiz edilmiştir. Sonuçlar, geri dönüştürülebilir hammadde konsantrasyonlarındaki %12'lik bir değişikliğin, her üç sürdürülebilirlik faktörü üzerinde doğrudan ve dolaylı etkileri olduğunu göstermiştir; çevresel faktörler üzerinde %13'lük bir artış, ekonomik faktörler üzerinde %6'lık bir artış ve sosyal faktörler üzerinde %5.4'lük bir etki yaratmıştır. Sonuç olarak, daha yüksek dereceli geri dönüştürülebilir malzemelerin kullanılması daha iyi çevresel, ekonomik ve sosyal sonuçlar sağlayacaktır. Ancak, piyasa dinamikleri, genel bütçe ve teknolojik kısıtlamalar gibi sınırlamaların mevcut olduğunu da unutmamak gerekir.

Anahtar Kelimeler: Sürdürülebilirlik, Geri Dönüştürülebilirlik

University	**: İstanbul Kültür University**
Institute	**: Institute of Graduate Studies**
Department	**: Industrial Engineering**
Program	**: Engineering Management**
Supervisor	**: Prof. Ayşe Tülin AKTİN**
Degree Awarded and Date	**: MS – February 2024**

ABSTRACT

Impact of Using Recycled Raw Material on Sustainability at a Packaging Manufacturer

Omar Aljouja

Sustainability is a crucial aspect of the earth's ecosystem, making sure resources are available for the next generation, while reducing the possibility of climate change. It is an ethical and obligation responsibility for all decision makers across the world, encourages accountable recourse usage, economic stability, and social equality, reassuring a balance between humans and nature which is essential for the long-term health and well-being of the earth. This study begins with preparing a questionnaire that includes economic, environmental, and social sustainability questions which is applied at a recyclable packaging manufacturer that uses different concentrations of recyclable raw material to measure its impact on the three pyramids of sustainability within the company. The questionnaire results are gathered and analyzed using Excel and GAMS/CPLEX solver. The results show that a 12% change in recyclable raw material concentrations has direct and indirect effects on all three sustainability factors; where it has a 13% increase on the environmental factors, a 6% increase on the economic factors, and a 5.4% impact on the social factors. In conclusion, utilizing higher grade recyclable materials will yield better environmental, economic, and social outcomes. However, it is important to acknowledge that limitations do exist such as market dynamics, overall budget, and technological constraints.

Keywords: Sustainability, Recyclability

1. INTRODUCTION

Sustainability is the ability to achieve the present requirements for life in a way that does not interfere or damage the future generations' capacity to attain the same or better life demands.

The idea of sustainability gain popularity and awareness in the second half of the 20^{th} century after the World Commission on Environment and Development published "Our Common Future" (1987), also known as the "Brundtland Report", which discussed sustainable development as "development that meets the need of the present without compromising the ability of future generations to meet their own needs".

Sustainability is important for many reasons such as environmental preservation, mitigation of climate change, resource conservation, social equality, economic stability, long-term planning and well-being, consumer awareness and global collaboration.

One way we can achieve sustainability is through recycling materials and products. Recycling has been used throughout history in many forms; humans reused materials such as copper, silver, and gold out of necessity due to its scarce nature, from earth's first day until in 1970, where the environmental legislation in many countries drove the expansion of recycling programs. This led to increased awareness of the importance of pollution reduction, waste management and the economic benefits of recycling and reprocessing.

In this day and age, it is noticed that a rapid increase in demand for eco-friendly recyclable products and materials arise, and many companies are trying to follow the trend of being sustainable. However, with increased demands for those products and high competition between companies, comes increased cost and technological challenges.

Some of the challenges facing recycling are contamination of materials during collecting and processing these materials, complexity of these materials that makes it very challenging to separate the recyclable from the unsalvageable components, lack of standardization which makes it difficult to create a universal solution that will solve the confusion for businesses and consumers on what and where recycling can be done, energy consumption where it could be difficult to acquire the energy required to recycle materials instead of creating new products from new raw ones, economic feasibility where sometimes it’s more expensive to gather and transport these recyclable material than acquiring virgin materials, technological difficulties in reprocessing plastics which leads to low grade materials because of the lack of high-tech recycling solutions, lack of public awareness and participation in recycling which leads to more wasted opportunities, and finally, the lack of infrastructures required to collect and recycle these materials.

The main aim of this research is to measure the effects of recyclable raw materials on the environmental, economic, and social sustainability of one company and how it can be mimicked and applied to other companies in different industries to achieve a higher standard of sustainability across the board. The company under consideration provides recyclable packaging products as in Figure 1, and recently started using a new recyclable raw material to produce these products. This study was conducted to evaluate the difference between the effects on sustainability of using the old and new raw material.

Figure 1. Packaging products made by the company

After an interview with the upper management, two questionnaires were proposed and implemented in the company. The people involved in these questionnaires held different positions to assure diverse and comprehensive answers that carried weight and gave logical meaning. The first questionnaire corresponded to the sustainability factors while using the first recyclable raw material “Material A” that is called “original polypropylene (pp) nonwoven” which was measured at 62 percent recyclable, and the second questionnaire answered the same questions but using the second recyclable raw material “Material B”, that is called “pp nonwoven converted from waste” measured at 74 percent recyclable. The results were collected and analyzed, where most of the sustainability factors showed a positive increase when using material B. While some factors did show a negative effect, some factors that displayed little to no change were classified as ineffective or irrelevant factors.

The study is organized as follows: Section 2 covers the relevant literature review about sustainability and recyclability studies, their statistical results that prove their success. Section 3 presents the methodology behind the study, the development of the questionnaires, the Excel model, and the mathematical model. Section 4 displays the implementation and results of the questionnaires, the mathematical model, and some optimization scenarios. Finally, Section 5 includes the conclusion and recommendations that can be implemented in future studies to yield more accurate results, such as more dependent and independent factors and limitations. The questionnaire applied in the company is given in Appendix A. On the other hand, Appendix B displays the GAMS input and output files of the mathematical models.

2. LITERATURE REVIEW

In recent times, sustainable development has been put on the forefront of attention due to concerns increasing about climate change and environmental crisis coupled with elevated levels of deprivation, inequalities between social classes and stress between communities (Giovannoni & Fabietti, 2013).

There are new challenges facing environmental sustainability, firstly the increased amounts of trash that is being produced all over the globe and secondly is the increased level of chemical and technological complexity it has (Tchobanoglous & Vergara, 2012).

It is mentioned that in industrial civilizations around 50 kg and 68 kg of packaging materials are used per person per year in Europe and the United States respectively, those packaging materials are made from a manufactured polymers called "plastics" (Thiounn & Smith, 2020).

Campos (2014) Mentioned that the main issue is not the large amount of waste produced by advanced countries because they tend to manage their waste efficiently, but the waste produced by the under-developed countries that pose a threat due to their inefficient and outdated waste management techniques.

Many firms have developed numerous sustainability programs to effectively decrease their toll on nature and reduce their new raw material utilization (Comyns & Figge, 2015) in response to the heightened attention from the communities, businesses, and regimes (Carroll & Shabana, 2010).

The need for a low-carbon eco-friendly financial system is progressively emphasized, reason behind is the scarce elements that are available on earth being the crucial component in products like magnets, lighting equipment, reloadable batteries and many more (Binnemans et al., 2013).

Baldé et al. (2017) stated that the current fast-paced life has encouraged the production of short-lived products because of the speed at which new technological developments are made, throwing away the old products and focusing on more automated electronic equipment and machinery, that is poising a big concern on the magnitude of e-waste created, its approximated that the electronic waste buildup was around 42 million tons in the year 2014.

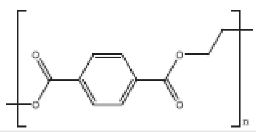
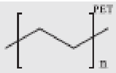
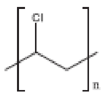
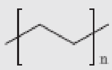
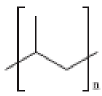
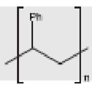
The amount of electronic waste recycled is merely 15% of the waste produced worldwide (Heacock et al., 2015). Recycling has the potential to cover a large portion of the planet's requirement of metals that can extracted from electronic devices which can include up to 60 metals in various products such as gold, copper, silver, platinum and many more (Namias, 2013)

It is yet unknown when an innovative technology for reprocessing plastics will be discovered or utilized, for the time being big markets and companies are still relying on environmentally harmful synthetic polymers that are made from petroleum derivatives (Jeong & Choi, 2019).

The volume of recycled plastics versus the available new goods are still relatively small which drove a lot of attempts to utilize and improve new reprocessing techniques (Datta & Kopczyńska, 2016).

To better facilitate and speed up the reprocessing procedure distinct types of plastics have been identified by the society of the plastics industry (SPI) in Table 1 and catalogued 1-6 (Rahimi & García, 2017).

Table 1. The SPI code identification number for polymer resins in plastic products, their structure, and common uses

SPI Code	Polymer	Structure	Uses
1	Poly(ethylene terephthalate) (PET)		Soda bottles, water bottles, medicine jars, and salad dressing bottles
2	High density polyethylene (HDPE)		Soap bottles, detergent and bleach containers, and trash bags
3	Polyvinyl chloride (PVC)		Plumbing pipes, cables, and fencing
4	Low density polyethylene (LDPE)		Cling wrap, sandwich bags, and grocery bags
5	Polypropylene (PP)		Reusable food containers, prescription bottles, and bottle caps
6	Polystyrene (PS)		Plastic utensils, packaging peanuts, and styrofoam

2.1. Recycling Plastics

Palmer (2009) explained that there are three ways plastic and plastic-infused materials are being recycled, those techniques have been introduced and encouraged due to the shear demand those materials have gotten, they were categorized as thermal, mechanical, and chemical as explained in Figure 2. The first part of any technique used to recycle plastics is crushing it into powder form, dividing them into two categorized, fine powder which consists of filler and synthetic polymer and rough powder which majorly include synthetic fiber (Pickering, 2006).

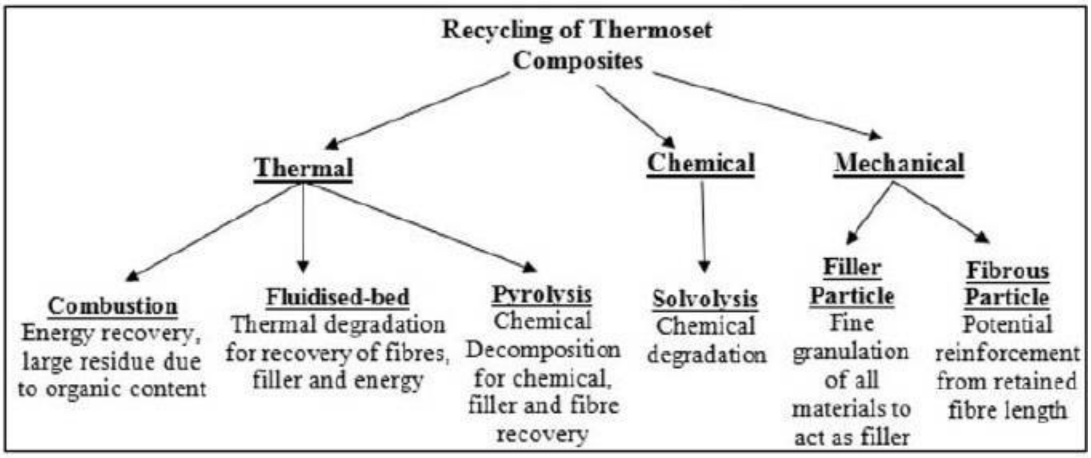


Figure 2. Recycling of thermoset composites using thermal, chemical, and mechanical methods

2.1.1. Mechanical Recycling

The simplest form of recycling which involves collecting, organizing, and processing the plastic waste such as glass reinforced plastic, metal infused plastics and polyethylene terephthalate (PET) derivatives and then crushing it, melting it, or molding it into new products (Oliveux et al., 2015). It is mentioned that the quality and the processing time of the finished product is directly proportioned to the size of the plastic waste, therefore the waste is divided into distinct size classes, this procedure is called pre-recycling (Nekouei et al., 2018; Wang et al., 2017).

2.1.2. Thermal Recycling

Hot temperatures are used as a second way of recycling plastics, its also separated to three types, first type is using fluidized bed thermal conversion, second type is thermal decomposition, and third type is microwave-initiated pyrolysis, but the later procedure has restricted availability (Krauklis et al., 2021). When the plastic is exposed to such high temperatures 450-700 ^{0}C the precious fibers are exposed while the insignificant material is vaporized or incinerated (Oliveux et al., 2015), it's worth mentioning that the exact temperature required depends on the material category where if improper heat is applied the valuable fibers can either be scorched if the temperature was low or its measurements are decreased (Rodrigues et al., 2014).

2.1.3. Chemical Recycling

Third and final way of dealing with plastics are through the use of acids, dissolvents and other chemicals, the suitable means to be used depend on the type of plastic selected, chemical recycling us usually done after mechanical recycling to maximize the surface area of the plastics (Asmatulu et al., 2013), after the chemical bath is done the residue is washed with either water or alcohol base substances to clean the surfaces of the restored fibers which have maximum mechanical properties (Pimenta & Pinho, 2011), however it's important to mention that chemical recycling has many disadvantages like it being harmful to the ecosystem even when properly used in a controlled environment (Van de Werken et al., 2019). Table 2 shows the advantages and disadvantages of thermal and chemical plastic recycling techniques (Lauzé, 2014).

Table 2. Advantages and disadvantages of chemical and thermal recycling methods of carbon fibers

Method	Advantages	Disadvantages
Pyrolysis	- By-products: useful for the other valuable polymeric materials. - Useful for mixed polymer recycling. - All the products from the process can be used. - Depolymerization of the polymer chain, producing sufficient energy content for pyrolysis. - By-products: used for production fuels and oils (high economic value).	- Pyrolysis has been performed with higher temperature. - The quality of the recovered fibers is, however, lower than in chemical recycling. - Main disadvantage after pyrolysis: an oxidization process is needed to remove the char deposited on the fiber surface. - The excess char results in reduced quality of bonding between the fibers and the new polymer. - Higher process cost and lower mechanical properties - Pyrolysis produces gases like CO and CO_2.
Solvolysis	- Most conventional process for chemical recycling: low temperature solvolysis - Obtained r-CF retrieved has very high mechanical properties and fiber length - Chemical recycling is the most efficient method for obtaining good-quality recycled fibers; it can be commercially promising.	- Some of the chemical solvents used in low temperature solvolysis can be toxic to the environment.
Supercritical Solvolysis	- Chemical recycling is the most environmentally friendly method (low toxicity, readily available, significantly lower processing cost compared to mechanical and thermal recycling). - Sub- or supercritical fluid solvolysis has been renowned for generating r-CFs with practically. - No mechanical degradation while employing nontoxic and low-cost solvents. - Supercritical solvolysis: clean CFs are recovered with similar mechanical properties to virgin fibers. - Undamaged CFs are obtained at comparatively low temperature, without using organic solvents or concentrated acids.	- Chemical recycling is the least eco-friendly method compared to mechanical and thermal recycling.

2.2. Recycling Effects on Sustainability

Recycling can be a terrific way to reduce carbon dioxide and other dangerous emissions which threaten our environment; therefore, many countries are encouraging the application of recycling to lower their carbon footprint (Khvorostyanaya, 2023). Ushatava is a Russian fashion brand based in Moscow, its main objective is improving their environmental impact by using sustainable production, they used recycled clothing to create high quality products that’s durable and long lasting, this serve two purposes, 1st is avoiding the overproduction of clothes “Fast Fashion” which greatly help the environment, 2nd is charging premium prices on these high-quality clothes so that the economic sustainability is not affected (Khvorostyanaya, 2021).

A study made in the European union showed that wastewater recycling had a significant role in improving environmental, economic, and social sustainability by collecting solid waste stuck in the sewage and recycling it, creating added resources, and providing new recycling jobs (Davide, 2016). In Spain authorities reported that the focus on recycling of solid waste have increased although there is considerable untapped potential in that service (Exposito & Velasco, 2018).

In Thailand, the Nonthaburi region stated that the recycling of wastewater had positive effects on all environmental, economic, and social sustainability explaining that the positive effects of the 24% wastewater recycling overshadowed the negative effects of the remaining 76% waste landfills (Menikpura et al., 2013).

A plan is suggested to encourage the efficient use of raw material by utilizing circular economy standards which include recycling used products, these actions continue to have positive effects on environmental sustainability (Stock et al., 2018; Müller & Hopf, 2017), Gielen et al. (2019) emphasized that sustainability through recycling is incredibly important, not only for the environment but to the social and economic growth for countries and companies, because nature has a finite number of resources available.

Growing need for energy is causing an increase in fuel prices which is harmful for the environment, in Asia rice which is considered the most famous grain grown thus, its residue can be used for energy generation benefiting the environment and the economy (Kumar et al., 2015). A study in India showed that instead of burning the crop residue that is estimated to be around five hundred metric tons annually (Devi et al., 2017) which release several harmful gases, recycling the residue can be beneficial to economic and environmental sustainability.

Extracting lithium from highly concentrated saltwater is fairly new which makes the production lithium ion batteries cheap and environmentally safe (Jiang et al., 2014) however, It's reported that if the waste of lithium-ion batteries is left without recycling it will cause great harm on the environment as well as people's vitality (Kang et al, 2013), therefore the collection is removal of these materials are important but because of its toxicity the storage capacity for such substances is limited and expensive, recycling it could be beneficial to the economy as well as the environment (Castillo et al., 2002; Dewulf et al., 2010).

Because of the complexity of these recycling processes its critical to know that there is still much research to be done to maximize the environmental, social, and economic sustainability (Benitez et al., 2020).

3. METHODOLOGY

In this section, the steps taken to produce the results of the study are explained, the methods used, and the programs utilized are shown, and the reason for each step is explained, flowchart in Figure 3 shows the steps and the data resource used in this study.

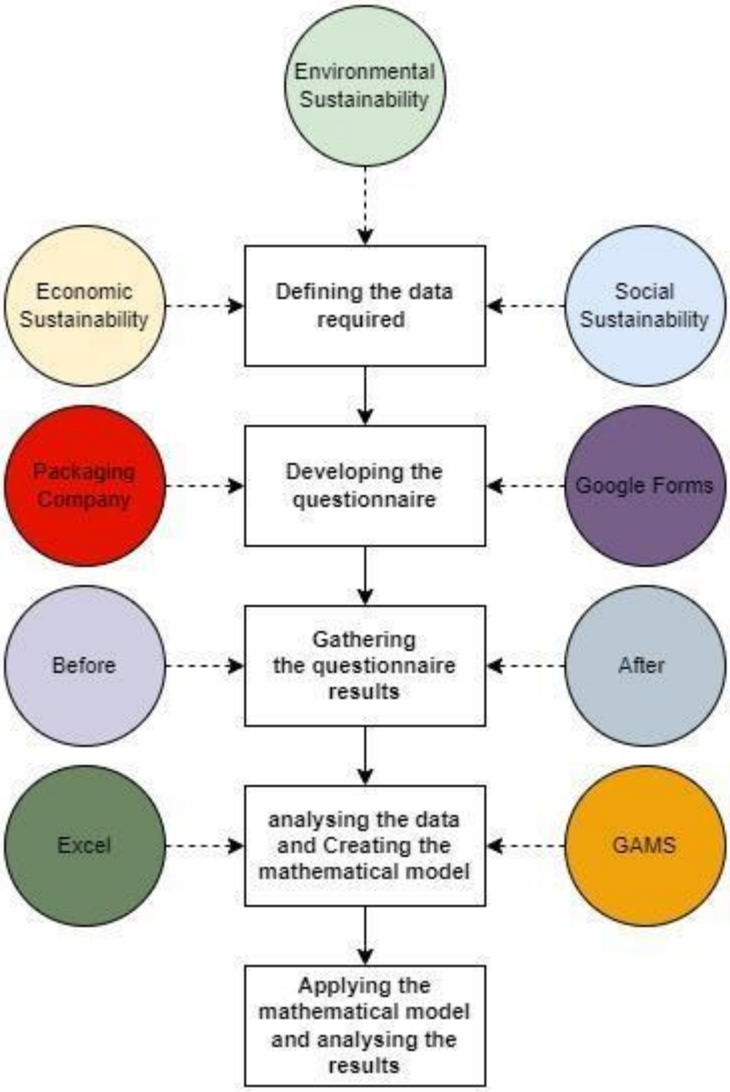


Figure 3. Steps done to acquire the results

The main goal behind this study is to observe the effects of changing into a more sustainable material on the environmental, economic, and social aspects.

3.1. Development of the Sustainability Questionnaire

An interview with the packaging manufacturer was conducted, each aspect of the production line was explained, and key variables were established, to make sure the three pillars of sustainable development are analyzed correctly a comprehensive but brief questionnaire had to be made, a previous questionnaire was used and adjusted to be compatible with this study (Aktin & Gergin, 2016).

Content of the questionnaire was as follows: seven questions about environmental factors, eight questions about economic factors and fourteen questions about social factors were inserted in the questionnaire, later six of the fourteen social questions were used because it was found that their results were independent of the study. The questionnaire is given in Appendix A.

The variables measured were about the following topics: product recyclability, percentage of recyclable material used, sustainability scale compared to competitors, company rating on national and international ecological standards, CO_2 emissions, water and electricity consumption, company market share and profitability, capital expenditure on sustainability, customer loyalty, turnover and growth rates, competitive prices, efficiency, employee’s years of service in the company, employees experience development , gender discrimination, employee age, salary, and legal requirements, employee equipment and first aid kit availability, job safety equipment, over time hours tracking, employee satisfaction, working hours, and injuries, help to new parents, social projects.

The questionnaire is separate to two parts, the “Before” part were answered for the use of the first recyclable material “original pp nonwoven” which was measured at 62 percent recyclable and the “After” part which answered the questions using the second material “pp nonwoven converted from waste” measured at 74 percent recyclable, then the “Before” and “After” parts were analyzed to find out the impact it had on the three pillars of sustainability.

The questionnaire was sent to the company and was answered using Google forms which is a survey administration software. The 10 people answering the questionnaire held distinct positions in the manufacturing company to try to get more comprehensive answers, and they held the following positions:

Quality control manager – 1 person

Quality control specialist – 2 people

Domestic sales department – 3 people

Export manager – 1 person

Export department – 3 people

After gathering the results of the questionnaire, each question had an answer from one to five and each question had ten answers, so a simple formula was used to analyze the results:

$X = 0.1(X_1) + 0.2(X_2) + 0.3(X_3) + 0.4(X_4) + 0.5(X_5)$

X = total value of the question

X_1 = number of people who answer with a value of 1

X_2 = number of people who answer with a value of 2

X_3 = number of people who answer with a value of 3

X_4 = number of people who answer with a value of 4

X_5 = number of people who answer with a value of 5

3.2. Excel Model

After the questionnaire was made, Excel was used to organize the questions in three sections, environmental, economic, and social factors. Each question was assumed to be a dependent variable other than the recyclable material used, which was assumed as the independent variable.

Each question was linked to a variable name and given a code so it can be easily recognized as shown in Table 3, the following are the variable names and codes:

Recyclable Material: *RM* (independent)

Product Recyclability: *PR* (dependent)

Sustainability Scale: *SC* (dependent)

National and International Standards: *NIS* (dependent)

CO_2 Emission: *CE* (dependent)

Water Consumption: *WC* (dependent)

Electricity Consumption: *EC* (dependent)

Market Share: *MS* (dependent)

Profitability: *PI* (dependent)

Sustainability Capital Expenditure: *SCE* (dependent)

Customer Loyalty: *CL* (dependent)

Turnover Rate: *TR* (dependent)

Growth Rate: *GR* (dependent)

Competitive Prices: *CP* (dependent)

Efficiency: *E* (dependent)

Employee Skill Development: *ESD* (dependent)

Employee Salary: *ES* (dependent)

Employee Legal Requirements: *ELR* (dependent)

Employee Satisfaction: *ESS* (dependent)

Work Hours: *WH* (dependent)

Work Injuries: *WI* (dependent)

Table 3. Survey questions and their variable codes

Environmental Factors	*Variables*
What percentage of your products are recyclable?	Product recyclability = PR
What percentage of your products are made from recyclable material ?	Recyclable Material = RM
Where do you stand on the sustainability scale compared to your competitors?	Sustainability Scale = SC
How can you rate your company in terms of complying with national and international ecological standards and certificates?	National and International Standards = NIS
What is your CO 2 emission level?	CO2 Emission = CE
What is your water consumption level?	Water Consumption = WC
What is your electricity consumption level?	Electricity Consumption = EC
Economical Factors	*Variables*
What is the company's market share?	Market Share = MS
What is the company's profitability?	Profitability = PI
What percentage of your capital expenditures are related to sustainability?	Sustainability Capital Expenditure = SCE
What is the customers' loyalty to your company?	Customer Loyalty = CL
What is the company's turnover rate?	Turnover Rate = TR
What is the company's growth rate?	Growth Rate = GR
Our products prices are competitive to other companies	Competitive Prices = CP
Our manufacturing processes are efficient	Efficiency = E
Social Factors	*Variables*
We support our employees to develop their professional skills	Employee Skill Development = ESD
Our employees' salaries are higher than the competitors' salaries	Employee salary = ES
All of our employees' legal requirements are complete (insurance, social security, etc.)	Employee Legal Requirements = ELR
Our employees are satisfied with their current position	Employee Satisfaction = ESS
Our company demands fewer working hours than our competitors	Work Hours = WH
Our company has fewer work injuries than other competitors	Work Injuries = WI

After that, a regression analysis was made using two points (corresponding to the "Before" and "After" cases). By employing these two variables, a formula for each variable was extracted to be later fed into the GAMS/CPLEX solver (2021) to find out the optimum recyclable material percentage.

3.3. Mathematical Models

To create the mathematical model, the CPLEX solver of GAMS (General Algebraic Modeling System) program was used, first the data collected from the "Before" and "After" questionnaire was analyzed, twenty dependent variables were assigned with the assumption that the recyclable material is independent, to construct a connection between the variables, a regression analysis was made using the change from the "Before" to the "After" results "two points", each dependent variable was connected with the independent variable "recyclable material" resulting in twenty formulas, Before putting these formulas in the GAMS/CPLEX solver, a limit had to be set, and because our questionnaire had limited answer scores one to five, the same limit was put in the program, the theory behind the limit is that naturally a variable cannot exceed a 100 percent which is a 5 in our mathematical model, therefore if a variable reached 5 the algorithm stops at that instants and give us the value of recyclable material along with the other variables value, then these formulas were put in the GAMS/CPLEX solver to find out different scenario results, first it was necessary to ensure that the formulas were accurate so a “Before” and “After” scenario was made, another scenario was made to find the optimum percentage for recyclable material, and other scenarios were done to include or exclude some variables or a full set of variables, e.g., environmental and economic variables only.

3.3.1. Model Parameters and Decision Variables

The parameters and decision variables of the mathematical model are defined below:

Parameter:

RM: Recyclable Material Value

Decision Variables:

PR: Product Recyclability

SC: Sustainability Scale

NIS: National and International Standards

CE: CO_2 Emission

WC: Water Consumption

EC: Electricity Consumption

MS: Market Share

PI: Profitability

SCE: Sustainability Capital Expenditure

CL: Customer Loyalty

TR: Turnover Rate

GR: Growth Rate

CP: Competitive Prices

E: Efficiency

ESD: Employee Skill Development

ES: Employee Salary

ELR: Employee Legal Requirements

ESS: Employee Satisfaction

WH: Work Hours

WI: Work Injuries

Z_1: Environmental Sustainability Value

Z_2: Economic Sustainability Value

Z_3: Social Sustainability Value

3.3.2. The Developed Model

The proposed sustainability model, which is developed as a linear programming (LP) model is presented below:

$$\max Z_1 = PR + SC + NIS + CE + WC + EC \tag{O1}$$

$$\max Z_2 = MS + PI + SCE + CL + TR + GR + CP + E \tag{O2}$$

$$\max Z_3 = ESD + ES + ELR + ESS + WH + WI \tag{O3}$$

$$\max Z = Z_1 + Z_2 + Z_3 \tag{O4}$$

Subject to:

$$PR = 0.5*RM + 2.55 \tag{1}$$

$$SC = 1.3333*RM - 0.6333 \tag{2}$$

$$NIS = 1.167*RM - 0.3167 \tag{3}$$

$$CE = 1.67*RM - 3.767 \tag{4}$$

$$WC = RM - 0.8 \tag{5}$$

$$EC = RM - 1.4 \tag{6}$$

$$MS = 0.67*RM + 2.13 \tag{7}$$

$$PI = 0.333*RM + 2.967 \tag{8}$$

$$SCE = 0.8333*RM + 0.9167 \tag{9}$$

$$CL = 0.167*RM + 3.683 \tag{10}$$

$TR = RM - 2.3$ (11)

$GR = -0.167*RM + 4.6167$ (12)

$CP = 0.333*RM + 2.467$ (13)

$E = 0.8333*RM + 0.4167$ (14)

$ESD = 0.333*RM + 1.67$ (15)

$ES = -0.167*RM + 3.4167$ (16)

$ELR = 0.5*RM + 3.05$ (17)

$ESS = 0.67*RM + 1.6333$ (18)

$WH = RM - 1.3$ (19)

$WI = -0.167*RM + 4.2167$ (20)

$PR, SC, NIS, \ldots, WI \leq 5$ (21)

$PR, SC, NIS, \ldots, WI \geq 0$ (22)

Objective functions (O1), (O2) and (O3) aim to maximize the total environmental, economic, and social factor scores, respectively. Objective function (O4) serves in the overall maximization of all factors. Equations (1)-(20) display the relationship between the "Recyclable Material Value (RM)" and the 20 independent variables extracted from the questionnaire. Their coefficients are determined from the regression analysis presented in Section 4.2. Finally, constraints (21) and (22) define the upper and lower bounds for the variables.

3.3.3. Mathematical Model 1 - Optimum Recyclable Material (Overall)

The first model was to find out the optimal "Recyclable Material Value (RM)" that maximizes all the sustainability variables. Thus, its objective function was defined as:

$\max Z = Z_1 + Z_2 + Z_3$ (O4)

3.3.4. Mathematical Model 2 - Optimum Recyclable Material (Environmental and Economic Factors)

The second model was to find out the optimal "Recyclable Material Value (RM)" that maximizes the environmental and economic pillars of sustainability, excluding the social sustainability variables. The following objective function was used in the model.

$$\max Z = Z_1 + Z_2 \tag{O5}$$

3.3.5. Mathematical Model 3 - Optimum Recyclable Material (Economic Factors)

Finally, the third model was to find out the optimal "Recyclable Material Value (RM)" that maximizes the economic variables of sustainability, excluding the environmental and social sustainability variables. Hence, its objective function was:

$$\max Z = MS + PI + SCE + CL + TR + GR + CP + E \tag{O2}$$

4. IMPLEMENTATION AND RESULTS

In this section, the results of the methodology will be shown and explained in detail.

4.1. Results of the Sustainability Questionnaire

The results of the "Before" and "After" questionnaire are shown for each question, some questions were considered irrelevant because of their values, or because the company mentioned that they were not related and their values were influenced by other events, these questions were excluded from this section.

4.1.1. Environmental Sustainability Questions

Figure 4 indicates that the recyclable finished products percentage increased by six percent using the new raw material, which is predictable since the new material has higher recyclability rate.

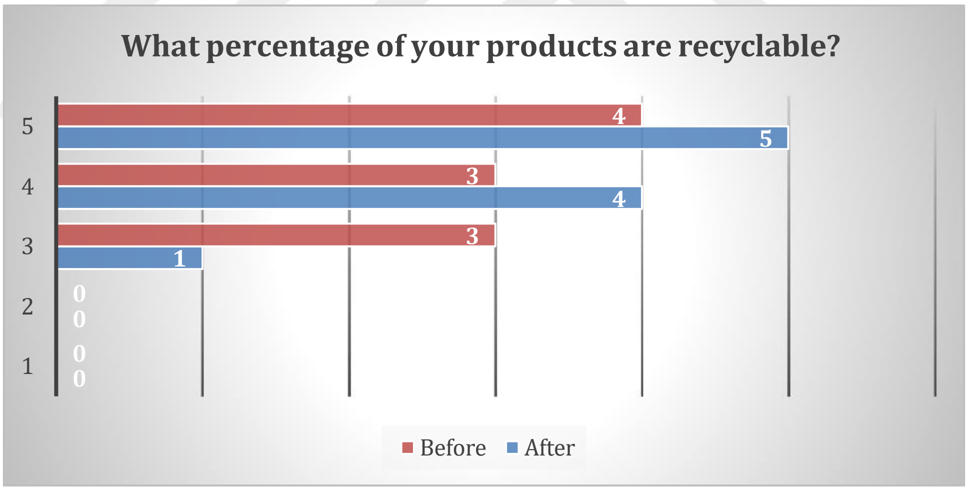


Figure 4. Result of the first question

Figure 5 shows that the new raw material is twelve percent more recyclable than the old raw material.

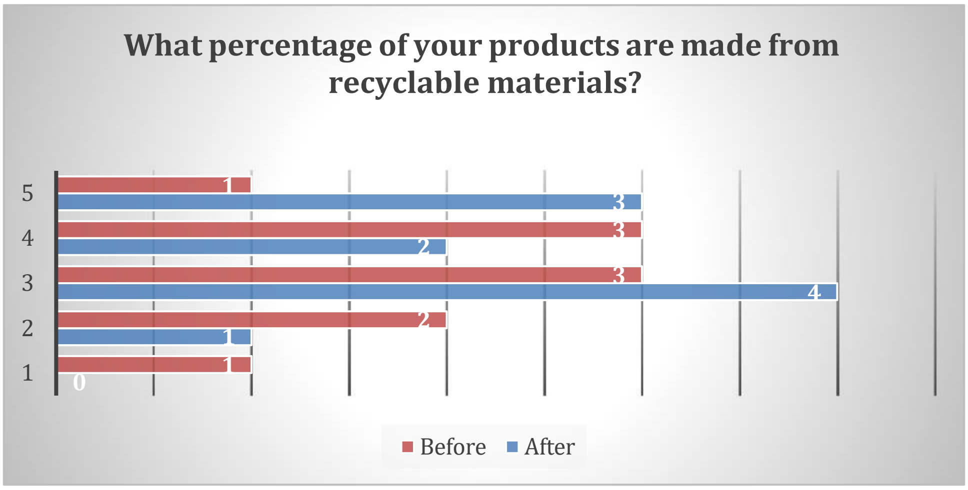


Figure 5. Result of the second question

Figure 6 displayed that the company was ranked sixteen percent higher using the new raw material in comparison to other companies in the same field, which indicates that the new material is among the highest rated material in the market.

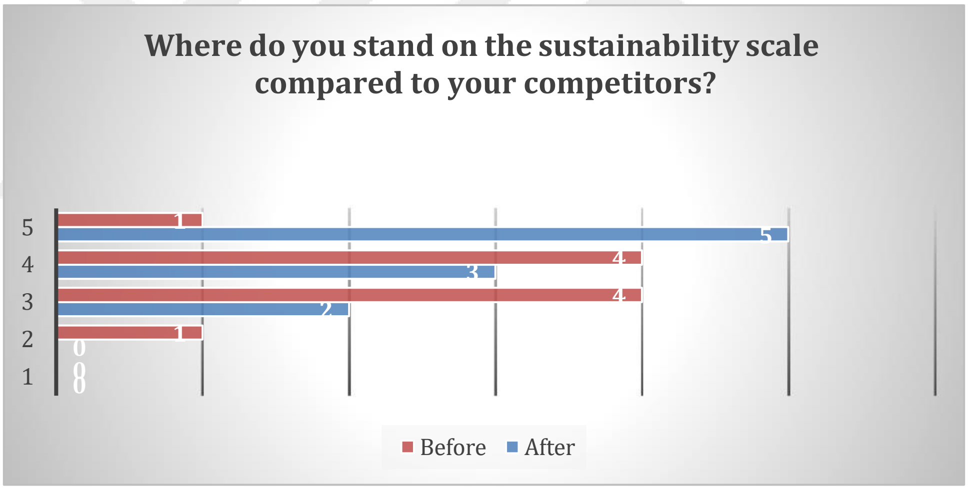


Figure 6. Result of the third question

Figure 7 indicates that the company climbed fourteen percent higher in the national and international ecological standards using the new raw material. These standards are based on water, electricity, and other consumptions, as well as CO_2 emissions.

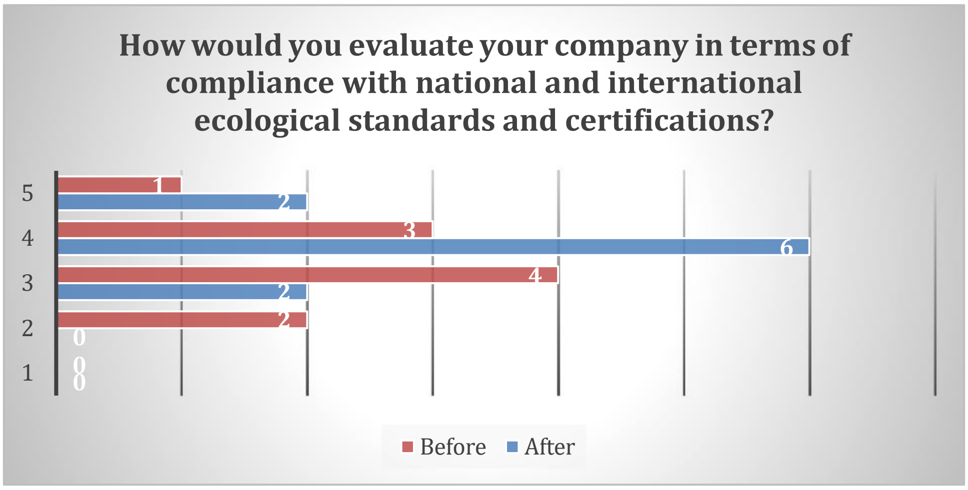


Figure 7. Result of the fourth question

Figure 8 showed that the carbon emission decreased twenty percent using the new raw material, which implies that the new material is cleaner and more eco-friendly.

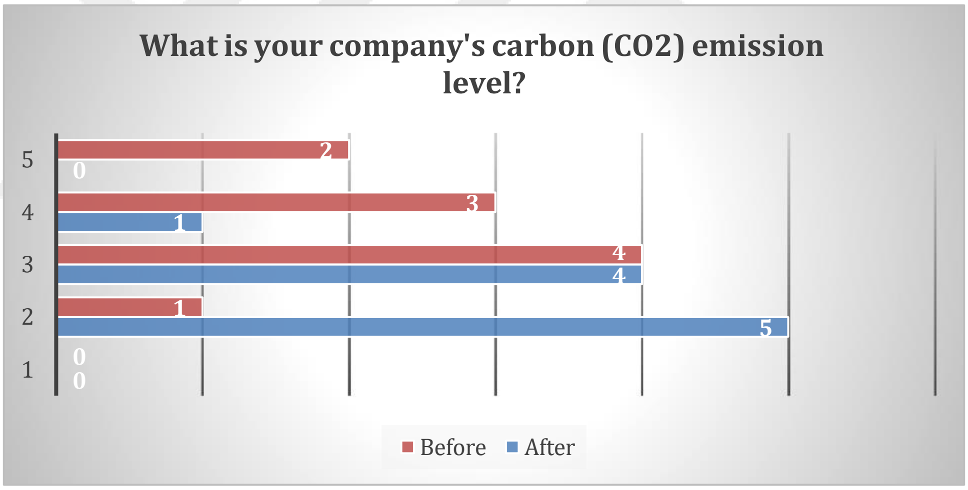


Figure 8. Result of the fifth question

Figure 9 showed that the company's water consumption decreased twelve percent using the new raw material, which also implies that the material is cleaner since water is used for disposing waste.

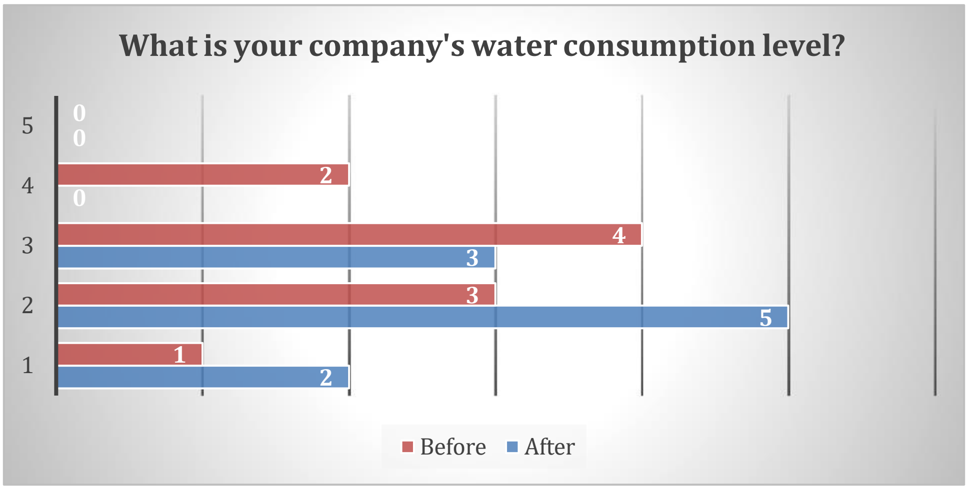


Figure 9. Result of the sixth question

Figure 10 displayed that the electricity consumption decreased twelve percent using the new recyclable material, electricity and water consumption going down helps with lowering the manufacturing cost.

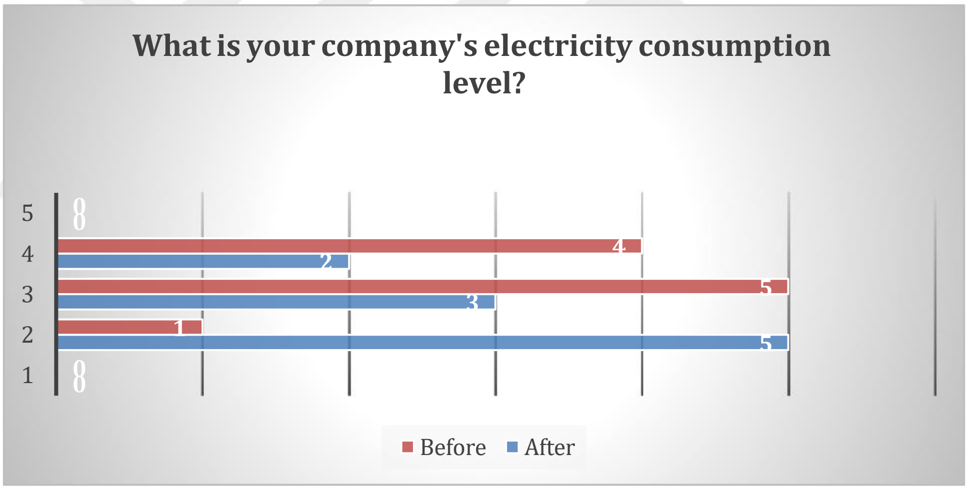


Figure 10. Result of the seventh question

By using the formula given in Section 3.1, the scores of the “Before” and “After” environmental sustainability questions were gathered as shown in Table 4, it was observed that the “After” results increased substantially around 13 percent increase using the new raw material, which was expected as the assumption was that the environmental sustainability would improve.

Table 4. "Before" and "After" scores of environmental sustainability survey

Questions	Score	
	Before	**After**
Environmental Factors		
1. What percentage of your products are recyclable?	4.10	4.40
2. What percentage of your products are made from recyclable materials?	3.10	3.70
3. Where do you stand on the sustainability scale compared to your competitors?	3.50	4.30
4. How can you rate your company in terms of complying with national and international ecological standards and certificates?	3.30	4.00
5. What is your CO_2 emission level?	1.40	2.40
6. What is your water consumption level?	2.30	2.90
7. What is your electricity consumption level?	1.70	2.30
Section Average	2.77	3.42

4.1.2. Economic Sustainability Questions

Figure 11 shows that the company's market share increased by eight percent using the new raw material, reflecting that the market demands more recyclable products.

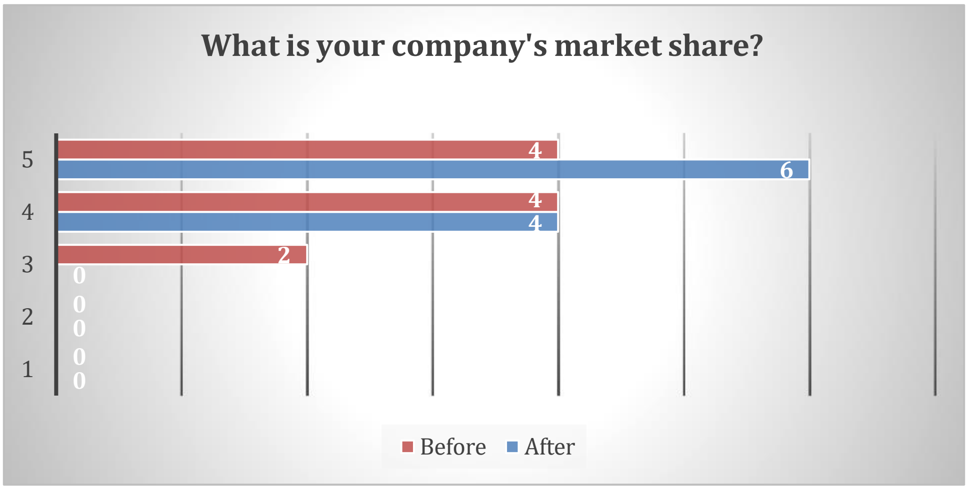


Figure 11. Result of the eighth question

Figure 12 indicates that profitability increased by four percent after using the new raw material, which could reflect lower consumptions.

Figure 12. Result of the ninth question

Figure 13 refers to the capital spent on sustainability which increased by ten percent when using the new raw material, due to higher rated material cost.

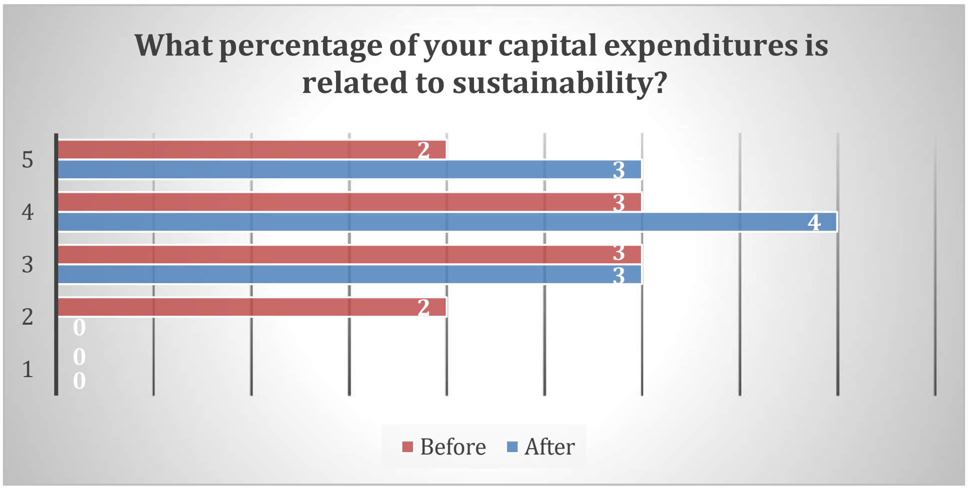


Figure 13. Result of the tenth question

Figure 14 shows that the customers loyalty did increase by two percent when using the new raw material, which also supports that the market demands more recyclable products.

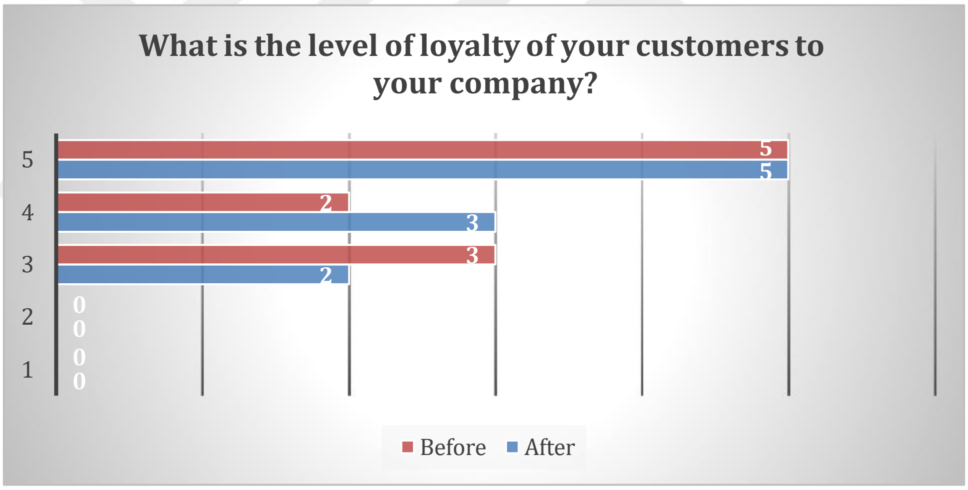


Figure 14. Result of the 11th question

Figure 15 showed that the turnover rate in the company decreased by twelve percent after using the new raw material, which helps with employment costs.

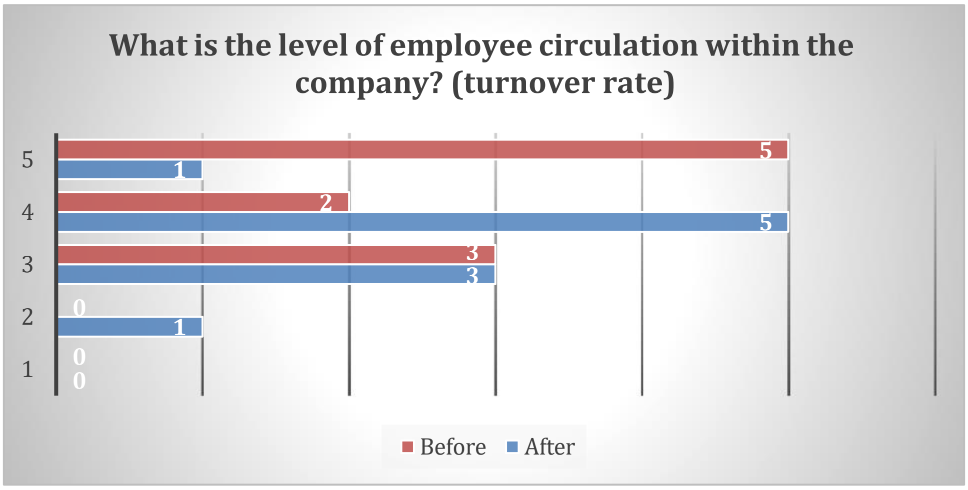


Figure 15. Result of the 12th question

Figure 16 indicated that the growth rate of the company decreased by two percent after using the new raw material, which implies that there is a limit to the growth that could be market size, overall budget, or other aspects.

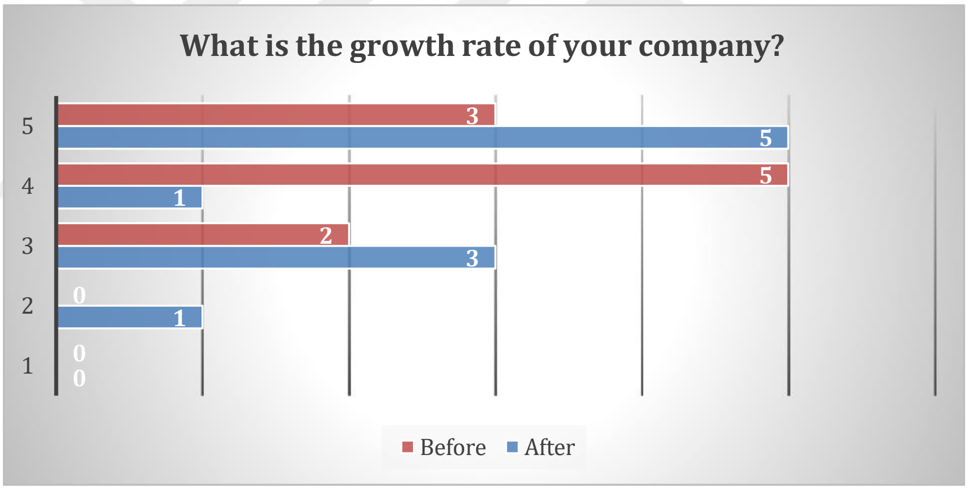


Figure 16. Result of the 13th question

Figure 17 shows that the product prices of the company decreased by four percent in comparison to their competitors after using the new raw material, direct effect of lower consumption costs.

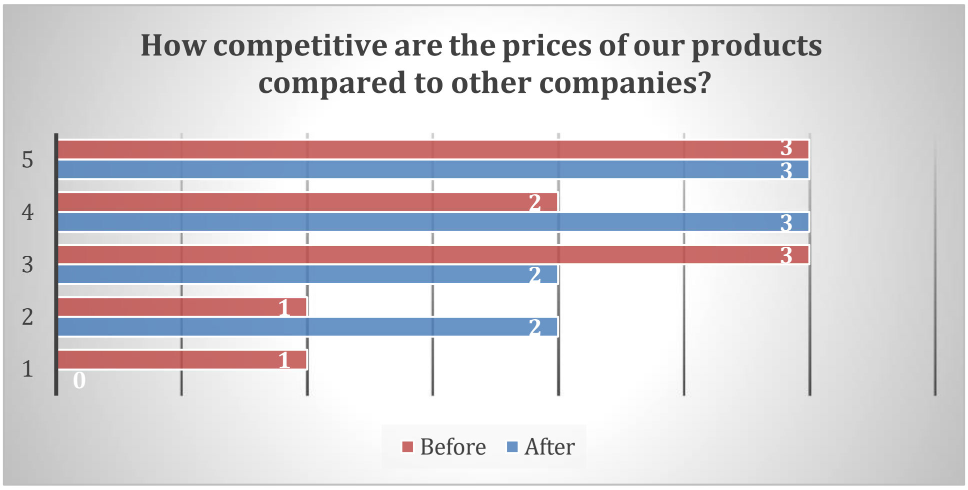


Figure 17. Result of the 14th question

Figure 18 indicated that the manufacturing efficiency of the company increased by ten percent after using the new raw material, direct effect of lower CO_2 emissions and water consumptions.

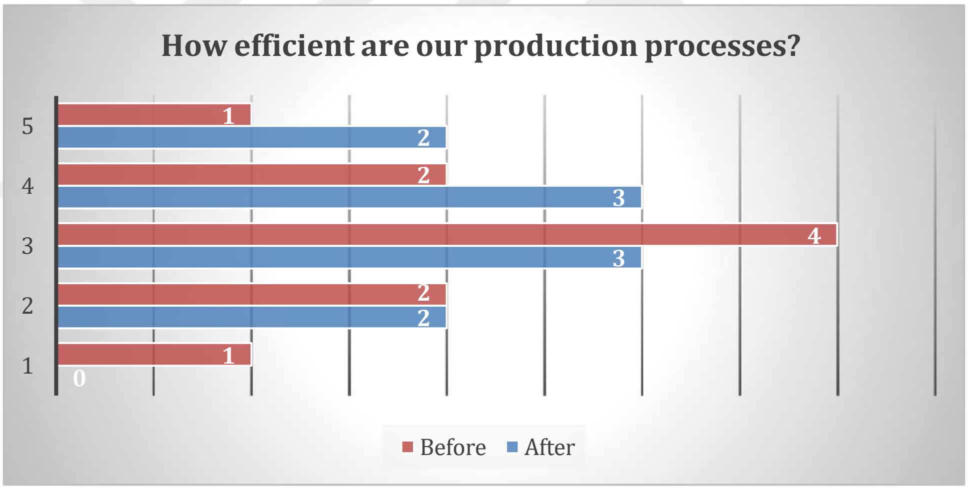


Figure 18. Result of the 15th question

Using the same formula, the scores of the "Before" and "After" economic sustainability questions were gathered as shown in Table 5, it was observed that the "After" results increased slightly around 6 percent increase using the new raw material, which was not expected as the assumption was that the economic sustainability would suffer.

Table 5. “Before” and “After” scores of economic sustainability survey

Questions	Score	
	Before	**After**
Economical Factors		
1. What is the company’s market share?	4.20	4.60
2. What is the company’s profitability?	4.00	4.20
3. What percentage of your capital expenditures are related to sustainability?	3.50	4.00
4. What is the customers’ loyalty to your company?	4.20	4.30
5. What is the company’s turnover rate?	0.80	1.40
6. What is the company’s growth rate?	4.10	4.00
7. Our products prices are competitive to other companies.	3.50	3.70
8. Our manufacturing processes are efficient.	3.00	3.50
Section Average	3.41	3.71

4.1.3. Social Sustainability Questions

Figure 19 indicates that the company’s support to employees increased by four percent after using the new raw material.

Figure 19. Result of the 16th question

Figure 20 shows that the employee’s salaries decreased by two percent after using the new raw material.

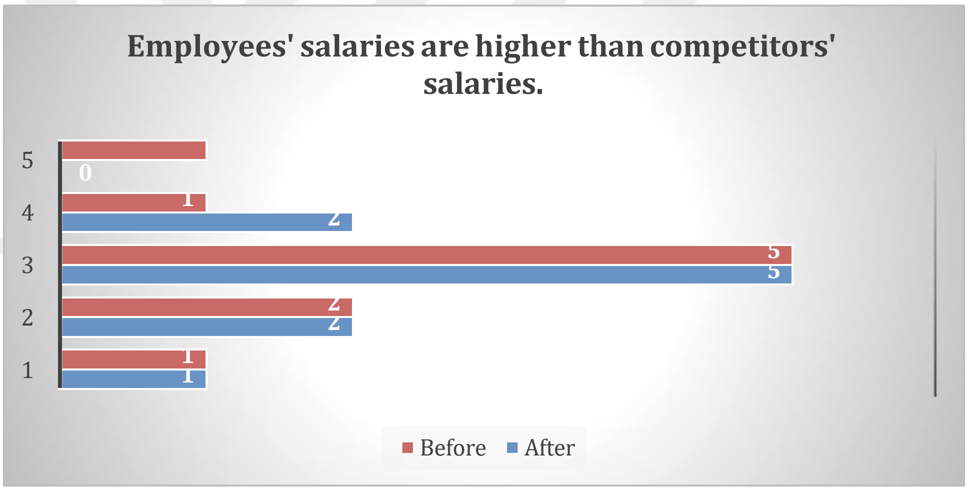


Figure 20. Result of the 17th question

Figure 21 indicates that the employee’s legal requirements accomplishment increased by six percent after using the new raw material.

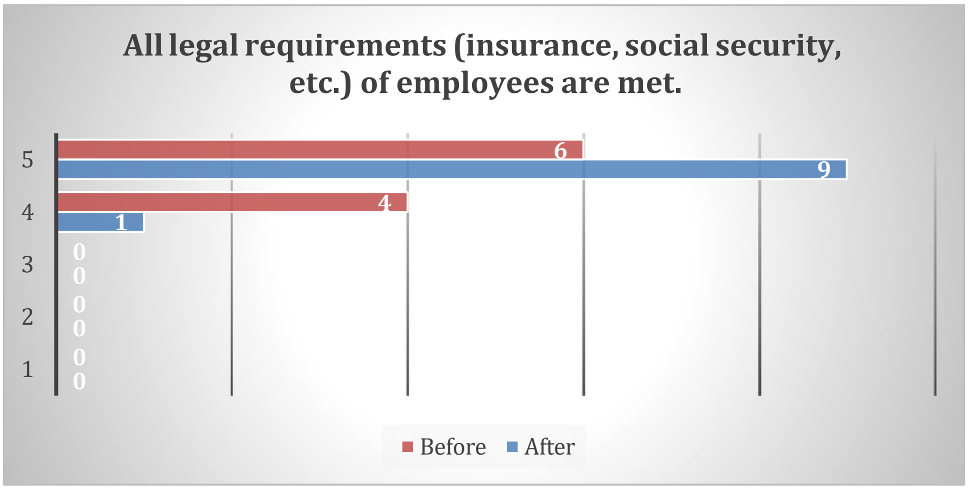


Figure 21. Result of the 18th question

Figure 22 shows that the employee's satisfaction increased by eight percent after using the new raw material.

Figure 22. Result of the 19th question

Figure 23 shows that the working hours of employees decreased by twelve percent in comparison to other companies after using the new raw material.

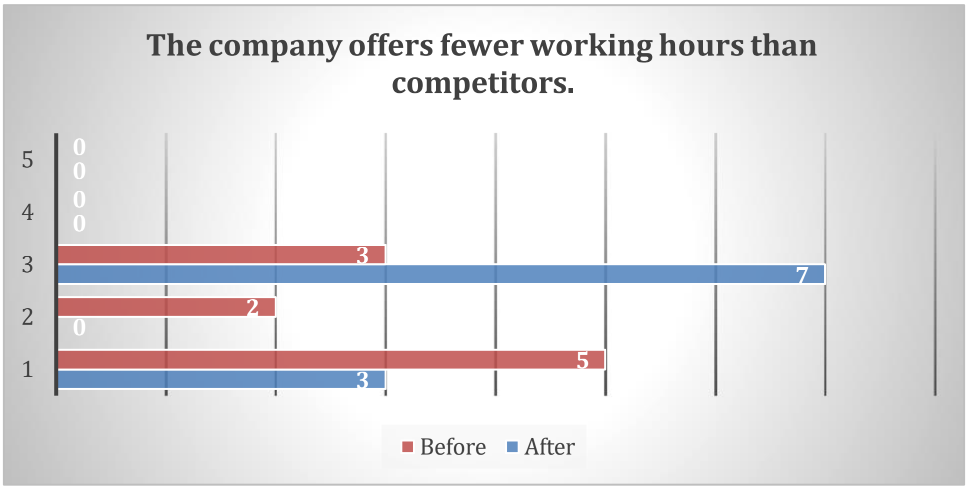


Figure 23. Result of the 20th question

Figure 24 indicates that the company had two percent more injuries after using the new raw material.

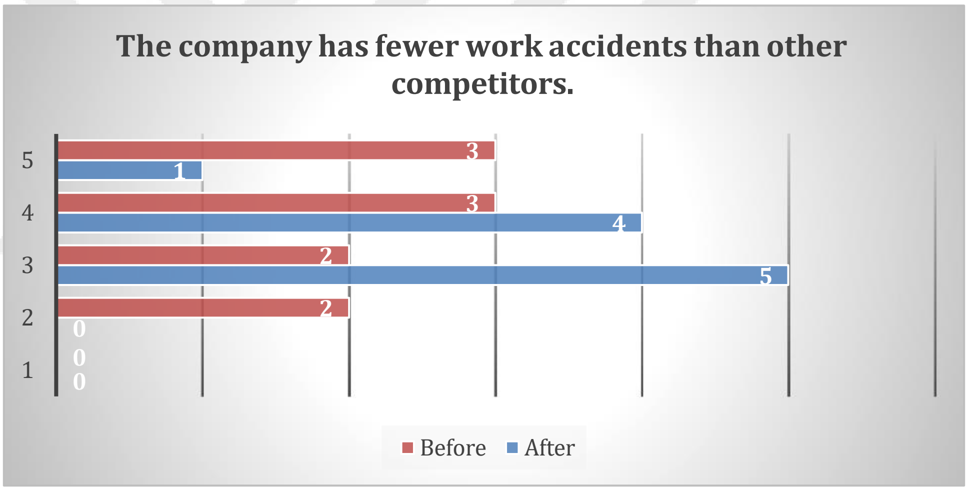


Figure 24. Result of the 21st question

Using the same formula, the scores of the "Before" and "After" social sustainability questions were gathered as shown in Table 6, it was observed that the "After" results increased slightly as well, around 5.4 percent increase using the new raw material, which was also not expected as the assumption was that the social sustainability would suffer too.

Table 6. "Before" and "After" scores of social sustainability survey

Questions	Score	
	Before	**After**
Social Factors		
1. We support our employees to develop their professional skills.	2.70	2.90
2. Our employees' salaries are higher than the competitors' salaries.	2.90	2.80
3. All of our employees' legal requirements are complete (insurance, social security, etc.).	4.60	4.90
4. Our employees are satisfied with their current position.	3.70	4.10
5. Our company demands fewer working hours than our competitors.	1.80	2.40
6. Our company has fewer work injuries than other competitors.	3.70	3.60
Section Average	3.37	3.64

Before starting the mathematical model, it was noticed that some of the survey questions had negative meanings such as CO_2 emissions, water and electricity consumptions, which means the higher the value the worst it is for the environmental sustainability, as well as turnover rate which also means if the value is high its negatively affecting the economic sustainability, to fix this issue and since the scale is out of five for these questions, the value five was deducted from these answers to give the opposite value which is positive.

4.2. Results of the Excel Model

After the values have been extracted and analyzed from the questionnaire, the numbers were put in the Excel program, and a regression analysis between each two points ("Before" and "After") was done to find the correlation between each variable and the recyclable raw material, the results of the regression analysis is as follows.

The linear equations (1)-(20) used in the proposed mathematical model, which are presented in Section 3.3.2, were extracted from the regression analysis. Tables 7 to 26 display the coefficients employed in these equations. Note that, all equations have the following form:

y= ax + b

y, x = variables

a = slope

b = y-intercept

Table 7. Product recyclability coefficient

ANOVA		
	df	*SS*
Regression	1	0.045
Residual	0	0
Total	1	0.045
	Coefficients	*Standard Error*
Intercept	2.55	0
RM	0.5	0

Table 8. Sustainability scale coefficient

ANOVA		
	df	*SS*
Regression	1	0.32
Residual	0	0
Total	1	0.32
	Coefficients	*Standard Error*
Intercept	-0.63333	0
RM	1.333333	0

Table 9. National and international scale coefficient

ANOVA		
	df	*SS*
Regression	1	0.245
Residual	0	0
Total	1	0.245
	Coefficients	*Standard Error*
Intercept	-0.31667	0
RM	1.166667	0

Table 10. CO_2 emission coefficient

ANOVA		
	df	*SS*
Regression	1	0.5
Residual	0	0
Total	1	0.5
	Coefficients	*Standard Error*
Intercept	-3.76667	0
RM	1.666667	0

Table 11. Water consumption coefficient

ANOVA		
	df	*SS*
Regression	1	0.18
Residual	0	0
Total	1	0.18
	Coefficients	*Standard Error*
Intercept	-0.8	0
RM	1	0

Table 12. Electricity consumption coefficient

ANOVA		
	df	*SS*
Regression	1	0.18
Residual	0	0
Total	1	0.18
	Coefficients	*Standard Error*
Intercept	-1.4	0
RM	1	0

Table 13. Company market share coefficient

ANOVA		
	df	*SS*
Regression	1	0.08
Residual	0	0
Total	1	0.08
	Coefficients	*Standard Error*
Intercept	2.133333	0
RM	0.666667	0

Table 14. Profitability coefficient

ANOVA		
	df	*SS*
Regression	1	0.02
Residual	0	0
Total	1	0.02
	Coefficients	*Standard Error*
Intercept	2.966667	0
RM	0.333333	0

Table 15. Sustainability capital expenditure coefficient

ANOVA		
	df	*SS*
Regression	1	0.125
Residual	0	0
Total	1	0.125
	Coefficients	*Standard Error*
Intercept	0.916667	0
RM	0.833333	0

Table 16. Customer loyalty coefficient

ANOVA		
	df	*SS*
Regression	1	0.005
Residual	0	0
Total	1	0.005
	Coefficients	*Standard Error*
Intercept	3.683333	0
RM	0.166667	0

Table 17. Turnover rate coefficient

ANOVA		
	df	*SS*
Regression	1	0.18
Residual	0	0
Total	1	0.18
	Coefficients	*Standard Error*
Intercept	-2.3	0
RM	1	0

Table 18. Growth rate coefficient

ANOVA		
	df	*SS*
Regression	1	0.005
Residual	0	0
Total	1	0.005
	Coefficients	*Standard Error*
Intercept	4.616667	0
RM	-0.16667	0

Table 19. Competitive prices coefficient

ANOVA		
	df	*SS*
Regression	1	0.02
Residual	0	0
Total	1	0.02
	Coefficients	*Standard Error*
Intercept	2.466667	0
RM	0.333333	0

Table 20. Efficiency coefficient

ANOVA		
	df	*SS*
Regression	1	0.125
Residual	0	0
Total	1	0.125
	Coefficients	*Standard Error*
Intercept	0.416667	0
RM	0.833333	0

Table 21. Employment skill development coefficient

ANOVA		
	df	*SS*
Regression	1	0.02
Residual	0	0
Total	1	0.02
	Coefficients	*Standard Error*
Intercept	1.666667	0
RM	0.333333	0

Table 22. Employment salary coefficient

ANOVA		
	df	*SS*
Regression	1	0.005
Residual	0	0
Total	1	0.005
	Coefficients	*Standard Error*
Intercept	3.416667	0
RM	-0.16667	0

Table 23. Employee legal requirement coefficient

ANOVA		
	df	*SS*
Regression	1	0.045
Residual	0	0
Total	1	0.045
	Coefficients	*Standard Error*
Intercept	3.05	0
RM	0.5	0

Table 24. Employee satisfaction coefficient

ANOVA		
	df	*SS*
Regression	1	0.08
Residual	0	0
Total	1	0.08
	Coefficients	*Standard Error*
Intercept	1.633333	0
RM	0.666667	0

Table 25. Work hours coefficient

ANOVA		
	df	*SS*
Regression	1	0.18
Residual	0	0
Total	1	0.18
	Coefficients	*Standard Error*
Intercept	-1.3	0
RM	1	0

Table 26. Work injuries coefficient

ANOVA		
	df	*SS*
Regression	1	0.005
Residual	0	0
Total	1	0.005
	Coefficients	*Standard Error*
Intercept	4.216667	0
RM	-0.16667	0

Consequently, an Excel sheet was constructed, and each variable and its relevant code, formula, and limit were organized as shown in Table 27.

Table 27. Excel equation output

Environmental Factors	*Variables*	*Formula*	*Limits*	*Note*
What percentage of your products are recyclable?	Product recyclability = PR	PR = 0.5*RM + 2.55	1 > X < 5	Dependent
What percentage of your products are made from recyclable material ?	Recyclable Material = RM	Constant	1 > X < 5	Independent
Where do you stand on the sustainability scale compared to your competitors?	Sustainability Scale = SC	SC = 1.3333*RM - 0.6333	1 > X < 5	Dependent
How can you rate your company in terms of complying with national and international ecological standards and certificates?	National and International Standards = NIS	NIS = 1.167*RM - 0.3167	1 > X < 5	Dependent
What is your CO 2 emission level?	CO2 Emission = CE	CE = 1.67*RM - 3.767	1 > X < 5	Dependent
What is your water consumption level?	Water Consumption = WC	WC = RM - 0.8	1 > X < 5	Dependent
What is your electricity consumption level?	Electricity Consumption = EC	EC = RM - 1.4	1 > X < 5	Dependent
Economical Factors	*Variables*	*Formula*	*Limits*	*Note*
What is the company's market share?	Market Share = MS	MS = 0.67*RM + 2.13	1 > X < 5	Dependent
What is the company's profitability?	Profitability = PI	PI = 0.333*RM + 2.967	1 > X < 5	Dependent
What percentage of your capital expenditures are related to sustainability?	Sustainability Capital Expenditure = SCE	SCE = 0.8333*RM + 0.9167	1 > X < 5	Dependent
What is the customers' loyalty to your company?	Customer Loyalty = CL	CL = 0.167*RM + 3.683	1 > X < 5	Dependent
What is the company's turnover rate?	Turnover Rate = TR	TR = RM - 2.3	1 > X < 5	Dependent
What is the company's growth rate?	Growth Rate = GR	GR = -0.167*RM + 4.6167	1 > X < 5	Dependent
Our products prices are competitive to other companies	Competitive Prices = CP	CP = 0.333*RM + 2.467	1 > X < 5	Dependent
Our manufacturing processes are efficient	Efficiency = E	E = 0.8333*RM + 0.4167	1 > X < 5	Dependent
Social Factors	*Variables*	*Formula*	*Limits*	*Note*
We support our employees to develop their professional skills	Employee Skill Development = ESD	ESD = 0.333*RM + 1.67	1 > X < 5	Dependent
Our employees' salaries are higher than the competitors' salaries	Employee salary = ES	ES = -0.167*RM + 3.4167	1 > X < 5	Dependent
All of our employees' legal requirements are complete (insurance, social security, etc.)	Employee Legal Requirements = ELR	ELR = 0.5*RM + 3.05	1 > X < 5	Dependent
Our employees are satisfied with their current position	Employee Satisfaction = ESS	ESS = 0.67*RM + 1.6333	1 > X < 5	Dependent
Our company demands fewer working hours than our competitors	Work Hours = WH	WH = RM - 1.3	1 > X < 5	Dependent
Our company has fewer work injuries than other competitors	Work Injuries = WI	WI = -0.167*RM + 4.2167	1 > X < 5	Dependent

4.3. Analysis of the “Before” and “After” Results

To make sure the equations would give accurate representation of the “Before” and “After” results of the questionnaire, GAMS/CPLEX solver was used and both cases were coded to be compiled and run.

Table 28 displays the “Before” results in which the value of the “Recyclable Material Value (RM)” was taken as 3.10 as indicated in Table 4. On the other hand, Table 29 shows the “After” results where the value of the “Recyclable Material Value (RM)” was taken as 3.70 as specified in Table 4.

Table 28. Result of the “Before” case

```
51 VARIABLE PR.L          =      4.100
   VARIABLE SC.L          =      3.500
   VARIABLE NIS.L         =      3.300
   VARIABLE CE.L          =      1.400
   VARIABLE WC.L          =      2.300
   VARIABLE EC.L          =      1.700
   VARIABLE MS.L          =      4.200
   VARIABLE PI.L          =      4.000
   VARIABLE SCE.L         =      3.500
   VARIABLE CL.L          =      4.200
   VARIABLE TR.L          =      0.800
   VARIABLE GR.L          =      4.100
   VARIABLE CP.L          =      3.500
   VARIABLE E.L           =      3.000
   VARIABLE ESD.L         =      2.700
   VARIABLE ES.L          =      2.900
   VARIABLE ELR.L         =      4.600
   VARIABLE ESS.L         =      3.700
   VARIABLE WH.L          =      1.800
   VARIABLE WI.L          =      3.700
```

Table 29. Result of the “After” case

```
51 VARIABLE PR.L          =      4.400
   VARIABLE SC.L          =      4.300
   VARIABLE NIS.L         =      4.000
   VARIABLE CE.L          =      2.400
   VARIABLE WC.L          =      2.900
   VARIABLE EC.L          =      2.300
   VARIABLE MS.L          =      4.600
   VARIABLE PI.L          =      4.200
   VARIABLE SCE.L         =      4.000
   VARIABLE CL.L          =      4.300
   VARIABLE TR.L          =      1.400
   VARIABLE GR.L          =      4.000
   VARIABLE CP.L          =      3.700
   VARIABLE E.L           =      3.500
   VARIABLE ESD.L         =      2.900
   VARIABLE ES.L          =      2.800
   VARIABLE ELR.L         =      4.900
   VARIABLE ESS.L         =      4.100
   VARIABLE WH.L          =      2.400
   VARIABLE WI.L          =      3.600
```

The equations gave the exact numbers in both questionnaires, this gave the green light to start different scenarios that can give us an optimum value for the recyclable raw material.

4.4. Mathematical Model Results

Now that the equations were accurate regarding the “Before” and “After” case, the same model was used for different cases. The input and output files of the models are provided in Appendix B.

4.4.1. Scenario 1 - Optimum Recyclable Material (Overall)

In the first scenario, Mathematical Model 1, with objective function (O4), which was presented in Section 3.3.3 was used. However, the “Recyclable Material Value (RM)” was no longer a parameter but was defined as a decision variable between [0,5].

The aim of that scenario was to find the appropriate raw material value at which the variables would reach the highest possible value without exceeding a hundred percent value (in the program that value was equal to five). The result of the first scenario is shown in Table 30.

Table 30. Scenario 1 results

103	VARIABLE RM.L	=	3.900
	VARIABLE PR.L	=	4.500
	VARIABLE SC.L	=	4.567
	VARIABLE NIS.L	=	4.233
	VARIABLE CE.L	=	2.733
	VARIABLE WC.L	=	3.100
	VARIABLE EC.L	=	2.500
	VARIABLE MS.L	=	4.733
	VARIABLE PI.L	=	4.267
	VARIABLE SCE.L	=	4.167
	VARIABLE CL.L	=	4.333
	VARIABLE TR.L	=	1.600
	VARIABLE GR.L	=	3.967
	VARIABLE CP.L	=	3.767
	VARIABLE E.L	=	3.667
	VARIABLE ESD.L	=	2.967
	VARIABLE ES.L	=	2.767
	VARIABLE ELR.L	=	5.000
	VARIABLE ESS.L	=	4.233
	VARIABLE WH.L	=	2.600
	VARIABLE WI.L	=	3.567
	VARIABLE Z1.L	=	21.633
	VARIABLE Z2.L	=	30.500
	VARIABLE Z3.L	=	21.133
	VARIABLE Z.L	=	73.267

Result of the first scenario gave a “Recyclable Material Value (RM)” of 3.900 which corresponds to 78 percent (3.900/5.000), and the variable that reached five which is the maximum value possible in this model was ELR which is the “Employee Legal Requirements”.

4.4.2. Scenario 2 - Optimum Recyclable Material (Environmental and Economic Factors)

In the second scenario, Mathematical Model 2, with objective function (O5), which was presented in Section 3.3.4 was used. Since the first variable to reach the value of five was in the social factors, the social factors were excluded from this scenario. Similar to the first scenario, the “Recyclable Material Value (RM)” was no longer a parameter but was defined as a decision variable between [0,5].

The result of the second scenario is shown in Table 31.

Table 31. Scenario 2 results

75	VARIABLE RM.L	=	4.225
	VARIABLE PR.L	=	4.663
	VARIABLE SC.L	=	5.000
	VARIABLE NIS.L	=	4.613
	VARIABLE CE.L	=	3.275
	VARIABLE WC.L	=	3.425
	VARIABLE EC.L	=	2.825
	VARIABLE MS.L	=	4.950
	VARIABLE PI.L	=	4.375
	VARIABLE SCE.L	=	4.438
	VARIABLE CL.L	=	4.388
	VARIABLE TR.L	=	1.925
	VARIABLE GR.L	=	3.912
	VARIABLE CP.L	=	3.875
	VARIABLE E.L	=	3.938
	VARIABLE Z1.L	=	23.800
	VARIABLE Z2.L	=	31.800
	VARIABLE Z.L	=	55.600

Result of the second scenario gave a “Recyclable Material Value (RM) of 4.225 which translates to 84.50 percent (4.225/5.000), and the variable that reached five was “Sustainability Scale (SC)” in comparison to other companies.

4.4.3. Scenario 3 - Optimum Recyclable Material (Economic Factors)

In the third scenario, Mathematical Model 3, with objective function (O2), which was presented in Section 3.3.5 was used. This scenario concentrates on economic sustainability only, since the second scenario capped at one of the environmental variables. Similar to the first and second scenarios, the “Recyclable Material Value (RM)” was no longer a parameter but was defined as a decision variable between [0,5].

The result of the third scenario is shown in Table 32.

Table 32. Scenario 3 results

46	VARIABLE RM.L	=	4.300
	VARIABLE MS.L	=	5.000
	VARIABLE PI.L	=	4.400
	VARIABLE SCE.L	=	4.500
	VARIABLE CL.L	=	4.400
	VARIABLE TR.L	=	2.000
	VARIABLE GR.L	=	3.900
	VARIABLE CP.L	=	3.900
	VARIABLE E.L	=	4.000
	VARIABLE Z.L	=	32.100

Result of the third scenario gave a “Recyclable Material Value (RM) of 4.300 (4.300/5.000) which corresponds to 86 percent, and the variable that reached five was the “Market Share (MS)”.

4.4.4. Final Remark

After gathering the results of all scenarios, they were shared with the company to get their opinion on the percentages. It should be noted that, the first scenario which gave a “Recyclable Material Value (RM)” percentage of 78% was in their opinion the most achievable one within their calculations of market trend, product cost and other hidden variables.

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, it is clear that recycling does not only positively affect the environmental sustainability of a business but can also supplement the social and economic sustainability directly and indirectly, as well.

Global warming and climate change can and will do serious damage to our planet causing it to be uninhabitable. To ensure that wouldn't happen, all aspects of sustainability have to be studied and protected to secure the resources and the tools for the generations to come and continue on the same footsteps. There are many ways to do so either by forcing a strict standard on manufacturing companies or by supporting the sustainable businesses, which will force the companies to comply and find new ways to sustain their operations.

The questionnaire that was conducted showed overall great effects on environmental sustaianbility, and significant effects on economic and social sustainability that would boost any business's popularity, which could lead to a higher boost in these two pyramids. The optimal result would be to create an intelligent AI supported model that is able to give adjustable variable suggestions in order to maximize all aspects of sustainability.

A twelve percent adjustment in recyclable raw materials made thirteen percent, six percent, and five and half percent improvement in environmental, economic and social sustainability, respectivly. In order to maximize the effects of recycling, a comprehensive study should be made to find new ways of recycling more complicated plastic compounds. Furthermore, the optimal recyclable raw material value can reach up to 78% percent , which is another four percent increase in recyclable material, and according to the company's analysis the 78% percent is accurate and achievable.

More variables can be included in future studies which were not possible in this study; such as, total budget, product cost, raw material cost and others, because the company, as well as many companies, would not share sensetive information that can be used by others to gain competitive advantage. These variables can be added by the company itself using a similar approach which will yield more accurate and realistic results that are viable to be applied in the market.

Circular economy is still a long way to go when it comes to plastics. This topic is fairly new, which means there is a lot of work to be done to be able to accurately measure the sustainability effects in businesses and the possible outcomes that's to be expected when adjusting the manufacturing formula. A lot of plastic compounds are yet to be recycled effectively, indicating that there is a big room for improvement and until we find a completely new material to use in these industries, focusing on recycling plastics should be a main priority for future sustainability studies.

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APPENDIX A- QUESTIONNAIRE FORM

This questionnaire is to be applied in the Before & After the usage of the new material

Environmental Factors

Give points between 1-5 to your company (1: absolutely disagree, 2: disagree, 3: neither agree nor disagree, 4: agree, 5: absolutely agree).

1. What percentage of your products are recyclable?

1 2 3 4 5

2. What percentage of your products are made from recyclable materials?

1 2 3 4 5

3. Compared to your competitors, where do you stand on the sustainability scale?

1 2 3 4 5

4. How can you rate your company in terms of complying with national and international ecological standards and certificates?

1 2 3 4 5

5. What is your CO_2 emission level?

1 2 3 4 5

6. What is your water consumption level?

1 2 3 4 5

7. What is your electricity consumption level?

1 2 3 4 5

Notes:

Economical Factors

Give points between 1-5 to your company (1: absolutely disagree, 2: disagree, 3: neither agree nor disagree, 4: agree, 5: absolutely agree).

1. What is the company's market share?

1 2 3 4 5

2. What is the company's profitability?

1 2 3 4 5

3. What percentage of your capital expenditures are related to sustainability?

1 2 3 4 5

4. What is the customers' loyalty to your company?

1 2 3 4 5

5. What is the company's turnover rate?

1 2 3 4 5

6. What is the company's growth rate?

1 2 3 4 5

7. Our products prices are competitive to other companies.

1 2 3 4 5

8. Our manufacturing processes are efficient.

1 2 3 4 5

Notes:

Social Factors

Give points between 1-5 to your company (1: absolutely disagree, 2: disagree, 3: neither agree nor disagree, 4: agree, 5: absolutely agree).

1. Our employees work in the company for many years.

   1 2 3 4 5

2. We support our employees to develop their professional skills.

   1 2 3 4 5

3. We do not apply gender discrimination in our hiring policy.

   1 2 3 4 5

4. Our employees' salaries are higher than the competitors' salaries.

   1 2 3 4 5

5. All of our employees are at legal working age.

   1 2 3 4 5

6. All of our employees' legal requirements are complete (insurance, social security, etc.).

   1 2 3 4 5

7. During production, necessary equipment for job safety is used (if needed; gloves, goggles, aprons, masks, etc.).

   1 2 3 4 5

8. We keep first aid kits in and around the production area.

   1 2 3 4 5

9. We record our staff's overtime hours.

   1 2 3 4 5

10. We support social responsibility projects (non-government organizations, UN projects, etc.).

    1 2 3 4 5

11. Our employees are satisfied with their current position.

    1 2 3 4 5

12. Our company offers help to newly parents.

    1 2 3 4 5

13. Our company demands fewer working hours than our competitors.

    1 2 3 4 5

14. Our company has fewer work injuries than other competitors.

    1 2 3 4 5

Notes:

APPENDIX B – GAMS INPUT AND OUTPUT FILES

Code and Result for “Before” Case

```
Variables RM , PR , SC, NIS , CE , WC , EC , MS , PI , SCE , CL , TR , GR , CP , E , ESD , ES , ELR , ESS , WH , WI,Z1,Z2,Z3,Z ;
Equations
con1,
con2,
con3,
con4,
con5,
con6,
con7,
con8,
con9,
con10,
con11,
con12,
con13,
con14,
con15,
con16,
con17,
con18,
con19,
con20,
con21,
con22,
con23,
con24,
con25;

Con1.. RM =e= 3.1 ;
Con2.. 0.5*RM + 2.55 =e= PR ;
Con3.. SC =e= 1.33333333333333*RM - 0.633333333333332;
Con4.. NIS =e= 1.16666666666667*RM - 0.316666666666667;
Con5..CE =e= 1.66666666666667*RM - 3.76666666666666;
Con6..WC  =e= RM - 0.8;
Con7..EC  =e= RM - 1.4;

Con8..MS =e= 0.666666666666666*RM + 2.13333333333334;
Con9..PI =e= 0.333333333333334*RM + 2.96666666666667;
Con10..SCE =e= 0.833333333333333*RM + 0.916666666666668;
Con11.. CL =e= 0.166666666666666*RM + 3.68333333333334;
Con12.. TR =e= RM - 2.3;
con13..GR =e= -0.166666666666666*RM + 4.61666666666666;
con14..CP =e= 0.333333333333334*RM + 2.46666666666667;
con15..E =e= 0.833333333333333*RM + 0.416666666666668;

con16..ESD =e= 0.333333333333333*RM + 1.66666666666667;
con17..ES =e= -0.166666666666667*RM + 3.41666666666667;
con18..ELR =e= 0.5*RM + 3.05;
con19..ESS =e= 0.666666666666666*RM + 1.63333333333334;
con20..WH =e= RM - 1.3;
con21..WI =e= -0.166666666666667*RM + 4.21666666666667;

con22..Z1 =e= PR+SC+NIS+CE+WC+EC;
con23..Z2 =e= MS+PI+SCE+CL+TR+GR+CP+E;
con24..Z3 =e= ESD+ES+ELR+ESS+WH+WI;
con25..Z =e= Z1+Z2+Z3
;
model mymodel /all/ ;
solve mymodel max Z using nlp;
display PR.L , SC.L , NIS.L ,  CE.L , WC.L , EC.L , MS.L , PI.L , SCE.L , CL.L , TR.L , GR.L , CP.L , E.L , ESD.L , ES.L , ELR.L , ESS.L , WH.L , WI.L,Z1.L,Z2.L,Z3.L,Z.L ;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
GAMS 45.3.0  c4c31d8a Nov 11, 2023          WEX-WEI x86 64bit/MS Windows - 01/10/24 11:24:54 Page 7
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----     60 VARIABLE PR.L                  =        4.100
            VARIABLE SC.L                  =        3.500
            VARIABLE NIS.L                 =        3.300
            VARIABLE CE.L                  =        1.400
            VARIABLE WC.L                  =        2.300
            VARIABLE EC.L                  =        1.700
            VARIABLE MS.L                  =        4.200
            VARIABLE PI.L                  =        4.000
            VARIABLE SCE.L                 =        3.500
            VARIABLE CL.L                  =        4.200
            VARIABLE TR.L                  =        0.800
            VARIABLE GR.L                  =        4.100
            VARIABLE CP.L                  =        3.500
            VARIABLE E.L                   =        3.000
            VARIABLE ESD.L                 =        2.700
            VARIABLE ES.L                  =        2.900
            VARIABLE ELR.L                 =        4.600
            VARIABLE ESS.L                 =        3.700
            VARIABLE WH.L                  =        1.800
            VARIABLE WI.L                  =        3.700
            VARIABLE Z1.L                  =       16.300
            VARIABLE Z2.L                  =       27.300
            VARIABLE Z3.L                  =       19.400
            VARIABLE Z.L                   =       63.000


EXECUTION TIME       =        0.031 SECONDS      3 MB  45.3.0 c4c31d8a WEX-WEI
```

Code and Result for “After” Case

```
Variables RM , PR , SC, NIS , CE , WC , EC , MS , PI , SCE , CL , TR , GR , CP , E , ESD , ES , ELR , ESS , WH , WI,Z1,Z2,Z3,Z ;
Equations
con1,
con2,
con3,
con4,
con5,
con6,
con7,
con8,
con9,
con10,
con11,
con12,
con13,
con14,
con15,
con16,
con17,
con18,
con19,
con20,
con21,
con22,
con23,
con24,
con25;

Con1.. RM =e= 3.7 ;
Con2.. 0.5*RM + 2.55 =e= PR ;
Con3.. SC =e= 1.33333333333333*RM - 0.633333333333332;
Con4.. NIS =e= 1.16666666666667*RM - 0.316666666666667;
Con5..CE =e= 1.66666666666667*RM - 3.76666666666666;
Con6..WC  =e= RM - 0.8;
Con7..EC  =e= RM - 1.4;

Con8..MS =e= 0.666666666666666*RM + 2.13333333333334;
Con9..PI =e= 0.333333333333334*RM + 2.96666666666667;
Con10..SCE =e= 0.833333333333333*RM + 0.916666666666668;
Con11.. CL =e= 0.166666666666666*RM + 3.68333333333334;
Con12.. TR =e= RM - 2.3;
con13..GR =e= -0.166666666666666*RM + 4.61666666666666;
con14..CP =e= 0.333333333333334*RM + 2.46666666666667;
con15..E =e= 0.833333333333333*RM + 0.416666666666668;

con16..ESD =e= 0.333333333333333*RM + 1.66666666666667;
con17..ES =e= -0.166666666666667*RM + 3.41666666666667;
con18..ELR =e= 0.5*RM + 3.05;
con19..ESS =e= 0.666666666666666*RM + 1.63333333333334;
con20..WH =e= RM - 1.3;
con21..WI =e= -0.166666666666667*RM + 4.21666666666667;

con22..Z1 =e= PR+SC+NIS+CE+WC+EC;
con23..Z2 =e= MS+PI+SCE+CL+TR+GR+CP+E;
con24..Z3 =e= ESD+ES+ELR+ESS+WH+WI;
con25..Z =e= Z1+Z2+Z3
;
model mymodel /all/ ;
solve mymodel max Z using nlp;
display PR.L , SC.L , NIS.L ,  CE.L , WC.L , EC.L , MS.L , PI.L , SCE.L , CL.L , TR.L , GR.L , CP.L , E.L , ESD.L , ES.L , ELR.L , ESS.L , WH.L , WI.L,Z1.L,Z2.L,Z3.L,Z.L ;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
GAMS 45.3.0  c4c31d8a Nov 11, 2023          WEX-WEI x86 64bit/MS Windows - 01/10/24 11:25:21 Page 7
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----     60 VARIABLE PR.L                  =        4.400
            VARIABLE SC.L                  =        4.300
            VARIABLE NIS.L                 =        4.000
            VARIABLE CE.L                  =        2.400
            VARIABLE WC.L                  =        2.900
            VARIABLE EC.L                  =        2.300
            VARIABLE MS.L                  =        4.600
            VARIABLE PI.L                  =        4.200
            VARIABLE SCE.L                 =        4.000
            VARIABLE CL.L                  =        4.300
            VARIABLE TR.L                  =        1.400
            VARIABLE GR.L                  =        4.000
            VARIABLE CP.L                  =        3.700
            VARIABLE E.L                   =        3.500
            VARIABLE ESD.L                 =        2.900
            VARIABLE ES.L                  =        2.800
            VARIABLE ELR.L                 =        4.900
            VARIABLE ESS.L                 =        4.100
            VARIABLE WH.L                  =        2.400
            VARIABLE WI.L                  =        3.600
            VARIABLE Z1.L                  =       20.300
            VARIABLE Z2.L                  =       29.700
            VARIABLE Z3.L                  =       20.700
            VARIABLE Z.L                   =       70.700



EXECUTION TIME       =        0.063 SECONDS      3 MB  45.3.0 c4c31d8a WEX-WEI
```

Code and Result for Scenario 1

```
Variables RM , PR , SC, NIS , CE , WC , EC , MS , PI , SCE , CL , TR , GR , CP , E , ESD , ES , ELR , ESS , WH , WI , Z1, Z2, Z3 ,Z;
Equations
con1,
con2,
con3,
con4,
con5,
con6,
con7,
con8,
con9,
con10,
con11,
con12,
con13,
con14,
con15,
con16,
con17,
con18,
con19,
con20,
con21,
con22,
con23,
con24,
con25,
con26,
con27,
con28,
con29,
con30,
con31,
con32,
con33,
con34,
con35,
con36,
con37,
con38
con39,
con40,
con41,
Con42,
con43,
con44,
con45;

Con1.. RM =L= 5 ;
Con2.. 0.5*RM + 2.55 =e= PR ;
Con3.. SC =e= 1.33333333333333*RM - 0.633333333333332;
Con4.. NIS =e= 1.16666666666667*RM - 0.316666666666667;
Con5..CE =e= 1.66666666666667*RM - 3.76666666666666;
Con6..WC  =e= RM - 0.8;
Con7..EC  =e= RM - 1.4;

Con8..MS =e= 0.666666666666666*RM + 2.13333333333334;
Con9..PI =e= 0.333333333333334*RM + 2.96666666666667;
Con10..SCE =e= 0.833333333333333*RM + 0.916666666666668;
Con11.. CL =e= 0.166666666666666*RM + 3.68333333333334;
Con12.. TR =e= RM - 2.3;
con13..GR =e= -0.166666666666666*RM + 4.61666666666666;
con14..CP =e= 0.333333333333334*RM + 2.46666666666667;
con15..E =e= 0.833333333333333*RM + 0.416666666666668;

con16..ESD =e= 0.333333333333333*RM + 1.66666666666667;
con17..ES =e= -0.166666666666667*RM + 3.41666666666667;
con18..ELR =e= 0.5*RM + 3.05;
con19..ESS =e= 0.666666666666666*RM + 1.63333333333334;
con20..WH =e= RM - 1.3;
con21..WI =e= -0.166666666666667*RM + 4.21666666666667;

con22..PR =L=5;
con23..SC =L=5;
con24..NIS =L=5;
con25..CE =L=5;
con26..WC=L=5;
con27..EC=L=5;

con28..MS =L=5;
con29..PI =L=5;
con30..SCE =L=5;
con31..CL =L=5;
con32..TR =L=5;
con33..GR =L=5;
con34..CP =L=5;
con35..E =L=5;

con36..ESD =L=5;
con37..ES =L=5;
con38..ELR =L=5;
con39..ESS =L=5;
con40..WH =L=5;
con41..WI =L=5;

con42..Z1 =e= PR+SC+NIS+CE+WC+EC;
con43..Z2 =e= MS+PI+SCE+CL+TR+GR+CP+E;
con44..Z3 =e= ESD+ES+ELR+ESS+WH+WI;
con45..Z =e= Z1+Z2+Z3;
;
model mymodel /all/ ;
solve mymodel max Z using nlp;
display RM.L , PR.L , SC.L , NIS.L ,  CE.L , WC.L , EC.L , MS.L , PI.L , SCE.L , CL.L , TR.L , GR.L , CP.L , E.L , ESD.L , ES.L , ELR.L , ESS.L , WH.L , WI.L ,Z1.L ,Z2.L ,Z3.L ,Z.L ;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
GAMS 45.3.0  c4c31d8a Nov 11, 2023          WEX-WEI x86 64bit/MS Windows - 01/10/24 11:25:39 Page 7
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----    103 VARIABLE RM.L                  =        3.900
            VARIABLE PR.L                  =        4.500
            VARIABLE SC.L                  =        4.567
            VARIABLE NIS.L                 =        4.233
            VARIABLE CE.L                  =        2.733
            VARIABLE WC.L                  =        3.100
            VARIABLE EC.L                  =        2.500
            VARIABLE MS.L                  =        4.733
            VARIABLE PI.L                  =        4.267
            VARIABLE SCE.L                 =        4.167
            VARIABLE CL.L                  =        4.333
            VARIABLE TR.L                  =        1.600
            VARIABLE GR.L                  =        3.967
            VARIABLE CP.L                  =        3.767
            VARIABLE E.L                   =        3.667
            VARIABLE ESD.L                 =        2.967
            VARIABLE ES.L                  =        2.767
            VARIABLE ELR.L                 =        5.000
            VARIABLE ESS.L                 =        4.233
            VARIABLE WH.L                  =        2.600
            VARIABLE WI.L                  =        3.567
            VARIABLE Z1.L                  =       21.633
            VARIABLE Z2.L                  =       30.500
            VARIABLE Z3.L                  =       21.133
            VARIABLE Z.L                   =       73.267


EXECUTION TIME       =        0.031 SECONDS      3 MB  45.3.0 c4c31d8a WEX-WEI


USER: GAMS Demo, for EULA and demo limitations see   G230930/0001CB-GEN
      https://www.gams.com/latest/docs/UG%5FLicense.html          DC0000
```

Code and Result for Scenario 2

```
Variables RM , PR , SC, NIS , CE , WC , EC , MS , PI , SCE , CL , TR , GR , CP , E , Z1, Z2,Z;
Equations
con1,
con2,
con3,
con4,
con5,
con6,
con7,
con8,
con9,
con10,
con11,
con12,
con13,
con14,
con15,
con16,
con17,
con18,
con19,
con20,
con21,
con22,
con23,
con24,
con25,
con26,
con27,
con28,
con29,
Con30,
con31,
con32;

Con1.. RM =L= 5 ;
Con2.. 0.5*RM + 2.55 =e= PR ;
Con3.. SC =e= 1.33333333333333*RM - 0.633333333333332;
Con4.. NIS =e= 1.16666666666667*RM - 0.316666666666667;
Con5..CE =e= 1.66666666666667*RM - 3.76666666666666;
Con6..WC  =e= RM - 0.8;
Con7..EC  =e= RM - 1.4;

Con8..MS =e= 0.666666666666666*RM + 2.13333333333334;
Con9..PI =e= 0.333333333333334*RM + 2.96666666666667;
Con10..SCE =e= 0.833333333333333*RM + 0.916666666666668;
Con11.. CL =e= 0.166666666666666*RM + 3.68333333333334;
Con12.. TR =e= RM - 2.3;
con13..GR =e= -0.166666666666666*RM + 4.61666666666666;
con14..CP =e= 0.333333333333334*RM + 2.46666666666667;
con15..E =e= 0.833333333333333*RM + 0.416666666666668;

con16..PR =L=5;
con17..SC =L=5;
con18..NIS =L=5;
con19..CE =L=5;
con20..WC=L=5;
con21..EC=L=5;

con22..MS =L=5;
con23..PI =L=5;
con24..SCE =L=5;
con25..CL =L=5;
con26..TR =L=5;
con27..GR =L=5;
```

```
con27..GR =L=5;
con28..CP =L=5;
con29..E =L=5;

con30..Z1 =e= PR+SC+NIS+CE+WC+EC ;
con31..Z2 =e= MS+PI+SCE+CL+TR+GR+CP+E ;
con32..Z =e= Z1+Z2 ;
;
model mymodel /all/ ;
solve mymodel max Z using nlp ;
display RM.L , PR.L , SC.L , NIS.L ,  CE.L , WC.L , EC.L , MS.L , PI.L , SCE.L , CL.L , TR.L , GR.L , CP.L , E.L , Z1.L ,Z2.L ,Z.L ;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
GAMS 45.3.0  c4c31d8a Nov 11, 2023          WEX-WEI x86 64bit/MS Windows - 01/10/24 11:25:45 Page 7
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----     75 VARIABLE RM.L                  =        4.225
            VARIABLE PR.L                  =        4.663
            VARIABLE SC.L                  =        5.000
            VARIABLE NIS.L                 =        4.613
            VARIABLE CE.L                  =        3.275
            VARIABLE WC.L                  =        3.425
            VARIABLE EC.L                  =        2.825
            VARIABLE MS.L                  =        4.950
            VARIABLE PI.L                  =        4.375
            VARIABLE SCE.L                 =        4.438
            VARIABLE CL.L                  =        4.388
            VARIABLE TR.L                  =        1.925
            VARIABLE GR.L                  =        3.912
            VARIABLE CP.L                  =        3.875
            VARIABLE E.L                   =        3.938
            VARIABLE Z1.L                  =       23.800
            VARIABLE Z2.L                  =       31.800
            VARIABLE Z.L                   =       55.600


EXECUTION TIME       =        0.031 SECONDS      3 MB  45.3.0 c4c31d8a WEX-WEI


USER: GAMS Demo, for EULA and demo limitations see   G230930/0001CB-GEN
      https://www.gams.com/latest/docs/UG%5FLicense.html         DC0000


**** FILE SUMMARY

Input      C:\Users\SATIS014\Desktop\thesis\GAMS REMADE\Scenario Two.gms
Output     C:\Users\SATIS014\Desktop\thesis\GAMS REMADE\Scenario Two.lst
```

Code and Result for Scenario 3

```
Variables RM , PR , SC, NIS , CE , WC , EC , MS , PI , SCE , CL , TR , GR , CP , E ,Z;
Equations
con1,
con2,
con3,
con4,
con5,
con6,
con7,
con8,
con9,
con10,
con11,
con12,
con13,
con14,
con15,
con16,
con17,
Con18;

Con1.. RM =L= 5 ;

Con2..MS =e= 0.666666666666666*RM + 2.13333333333334;
Con3..PI =e= 0.333333333333334*RM + 2.96666666666667;
Con4..SCE =e= 0.833333333333333*RM + 0.916666666666668;
Con5.. CL =e= 0.166666666666666*RM + 3.68333333333334;
Con6.. TR =e= RM - 2.3;
con7..GR =e= -0.166666666666666*RM + 4.61666666666666;
con8..CP =e= 0.333333333333334*RM + 2.46666666666667;
con9..E =e= 0.833333333333333*RM + 0.416666666666668;

con10..MS =L=5;
con11..PI =L=5;
con12..SCE =L=5;
con13..CL =L=5;
con14..TR =L=5;
con15..GR =L=5;
con16..CP =L=5;
con17..E =L=5;

con18..Z =e= MS+PI+SCE+CL+TR+GR+CP+E;
;
model mymodel /all/ ;
solve mymodel max Z using nlp ;
display RM.L , MS.L , PI.L , SCE.L , CL.L , TR.L , GR.L , CP.L , E.L ,Z.L ;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
GAMS 45.3.0  c4c31d8a Nov 11, 2023          WEX-WEI x86 64bit/MS Windows - 01/10/24 11:25:54 Page 7
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----     46 VARIABLE RM.L                  =        4.300
            VARIABLE MS.L                  =        5.000
            VARIABLE PI.L                  =        4.400
            VARIABLE SCE.L                 =        4.500
            VARIABLE CL.L                  =        4.400
            VARIABLE TR.L                  =        2.000
            VARIABLE GR.L                  =        3.900
            VARIABLE CP.L                  =        3.900
            VARIABLE E.L                   =        4.000
            VARIABLE Z.L                   =       32.100


EXECUTION TIME       =        0.047 SECONDS      3 MB  45.3.0 c4c31d8a WEX-WEI


USER: GAMS Demo, for EULA and demo limitations see   G230930/0001CB-GEN
      https://www.gams.com/latest/docs/UG%5FLicense.html         DC0000


**** FILE SUMMARY

Input      C:\Users\SATIS014\Desktop\thesis\GAMS REMADE\Scenario three.gms
Output     C:\Users\SATIS014\Desktop\thesis\GAMS REMADE\Scenario three.lst
```