T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

OPTIMIZING CONSUMER PURCHASES FOR COST AND ENVIRONMENTAL IMPACT THROUGH MULTI-OBJECTIVE LINEAR PROGRAMMING WITH A SUSTAINABILITY PERSPECTIVE

BEYHAN SEREN TÜSÜN SAPAN

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF INDUSTRIAL ENGINEERING

ADVISOR: ASSIST.PROF.DR. AHMED BURAK PAÇ

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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ÇOK AMAÇLI DOĞRUSAL PROGRAMLAMA İLE MALİYET VE ÇEVRESEL ETKİ AÇISINDAN TÜKETİCİ SATIN ALIMLARININ SÜRDÜRÜLEBİLİRLİK PERSPEKTİFİYLE OPTİMİZASYONU

BEYHAN SEREN TÜSÜN SAPAN

YÜKSEK LİSANS TEZİ
ENDÜSTRİ MÜHENDİSLİĞİ ANABİLİM DALI

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ABSTRACT

The impacts of global warming are becoming increasingly evident, leading to growing environmental awareness through various protocols and regulations. In today's economic system, the sustainability features of products are prominently highlighted, yet there is no specific analytical decision-making model tailored to individual shopping preferences in supermarkets. This thesis develops a multi-objective linear programming (MOLP) model to optimize consumer purchasing decisions by balancing cost and environmental impact. The model uses real-world data from Environmental Product Declarations (EPD) and product prices to guide sustainable shopping decisions. By employing the Pareto efficient frontier, the model visualizes the trade-offs between cost and environmental impact, helping consumers make informed choices. Additionally, a synthetic dataset that models different societal dispositions through Beta distributions of cost-environment orientation parameters is utilized.This research aims to demonstrate the potential of optimization methods as effective tools for promoting sustainable consumer behavior.

Keywords: Sustainability, Sustainable Consumption, Optimization, Multi-Objective Linear Programming (MOLP), Retail Shopping

ÖZET

Küresel ısınmanın etkileri giderek daha belirgin hale geldikçe, çevresel farkındalık çeşitli protokoller ve düzenlemeler yoluyla artmaktadır. Günümüz ekonomik sisteminde, ürünlerin sürdürülebilirlik özellikleri öne çıkmaktadır, ancak süpermarketlerde bireysel alışveriş tercihlerini hedefleyen özel bir analitik karar verme modeli bulunmamaktadır. Bu tez, tüketici satın alma kararlarını maliyet ve çevresel etkiyi dengeleyerek optimize etmek için çok amaçlı doğrusal programlama (MOLP) modeli geliştirmektedir. Model, Çevresel Ürün Beyanları (EPD) ve ürün fiyatlarına ilişkin gerçek dünya verilerini kullanarak sürdürülebilir alışveriş kararlarına rehberlik eder. Pareto verimli sınırını kullanarak, model maliyet ve çevresel etki arasındaki ödünleşmeleri görselleştirir, böylece tüketicilerin bilinçli seçimler yapmasına yardımcı olur. Ayrıca bu çalışmada, maliyet-çevre yönelimi parametrelerinin Beta dağılımları aracılığıyla farklı toplumsal eğilimleri modelleyen sentetik bir veri kümesi kullanılmıştır. Bu tez, optimizasyon yöntemlerinin sürdürülebilir tüketici davranışını teşvik etmek için etkili araçlar olarak potansiyelini göstererek literatürdeki bir boşluğu doldurmayı amaçlamaktadır.

Anahtar Kelimeler: Sürdürülebilirlik, Sürdürülebilir Tüketim, Optimizasyon, Çok Amaçlı Doğrusal Programlama, Perakende Alışveriş, Çevresel Etki

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LIST OF SYMBOLS AND ABBREVIATIONS

α	: Shape parameter of Beta distributions
β	: Second shape parameter of Beta distributions
C_{ik}	: The price of model *k* in category *i*.
C_{ij}	: Cost of purchasing product *j* from supplier *i*
D_j	: Demand for product *j*.
E_{ijk}	: Environmental impact of purchasing product *j* from supplier *i* under criterion *k*.
e_{ik}	: The environmental impact of model *k* in category *i*.
FA	: Fuzzy Algorithm
GA	: Generic Algorithm
GHG	: Greenhouse Gas
GRI	: The Global Reporting Initiative
GWP	: Global Warming Potential
HA	: Hybrid Algorithm
I	: Product Categories (e.g., milk, bread, eggs)
i	: i is an element of I
IPCC	: The Intergovernmental Panel on Climate Change
IPCC	: The Intergovernmental Panel on Climate Change
J	: Product
j	: *j* is an element of J
K_i	: Brand and Model within each product category *i*
kg CO_2e	: CO_2 Equivalent
LCA	: Life Cycle Assessment
LP	: Linear Programming
M_i	: The minimum required quantity for the product category
MILP	: Mixed Integer Linear Programming
MINLP	: Mixed Integer Nonlinear Programming
$minZ$	: Minimization of the objective function
N_2O	: Nitrous Oxide
NLP	: Nonlinear Programming
S_{ijk}	: Social impact of purchasing product *j* from supplier *i* under *k*.
SC_{ijk}	:Supply capacity of supplier *i* for product *j*.
T_{jk}	:Threshold for the maximum allowable social impact for *j* under *k*.
v_{ik}	: Volume or quantity of product *k* category *i*
w1	: Weight assigned to cost in the objective function
w2	: Weight assigned to environmental impact in the objective function
W_k	: Weight or importance of sustainability criterion *k*.
x_{ij}	: Quantity of product j to be purchased from supplier i
x_{ik}	: Decision variable.
y_i	: Binary variable, 1 if supplier i is selected, 0 otherwise
Z	: Objective function value to be minimized

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1. INTRODUCTION

As the impacts of global warming become increasingly evident across various regions, environmental awareness driven by protocols, agreements, and regulations is being propagated from the state level downwards. In today's economic system, where firms operate based on supply-demand balance, sustainability features in products are prominently highlighted. Although we have various tools to understand and measure the three dimensions of sustainability, there is no analytical decision-making model specifically reduced to our shopping preferences, particularly in supermarkets.

The primary interface between individuals and sustainable decision-making is the purchase of products and/or services that undergo various stages. These life cycle phases extend into the realm of individual households, physical stores, and e-commerce platforms. Throughout these stages, products and services generate environmental, economic, and social impacts on systems. With growing interest in greener products and access to product information, sustainability has become crucial for retail companies aiming to attract customers.

For sustainable shopping, it is essential to buy as few products as possible and to focus on extending their lifespan. The analytical consideration of environmental criteria in purchasing decisions is increasingly seen in producers' supplier selections. However, it has been observed that we lack similar information when selecting everyday essential items such as food and personal care products in supermarkets. This thesis develops a multi-objective linear programming model that addresses the environmental and economic dimensions of products at the end-user level, aiming to guide sustainable shopping decisions.

2. SUSTAINABILITY

2.1. Climate Change and Sustainability

Understanding of the effect of CO2(carbon dioxide) and greenhouse gases on the climate goes back to the 19th Century (Arrhenius, 1896). Over more than a century, numerous scientific research studies by institutes and companies have examined the effects of industrial systems and greenhouse gases on the Earth, with action plans beginning in the 21st century. Today, there is no scientific doubt that human-sourced industrial activities are warming the planet and creating risks to human life(The Intergovernmental Panel on Climate Change (IPCC), n.d.). Climate change refers to long-term changes in Earth's climate, often associated with global temperatures, extreme weather events, and more, due to high concentrations of greenhouse gases such as CO2, methane (CH4), nitrous oxide (N2O), and fluorinated gases.

Global GHG(Greenhouse Gas)emissions are categorized into five sectors by the IPCC which are Energy Systems, Industry, AFOLU (Agriculture, Forestry, and Other Land Use), Transport, and Buildings. There are several reports on calculating sector emissions.

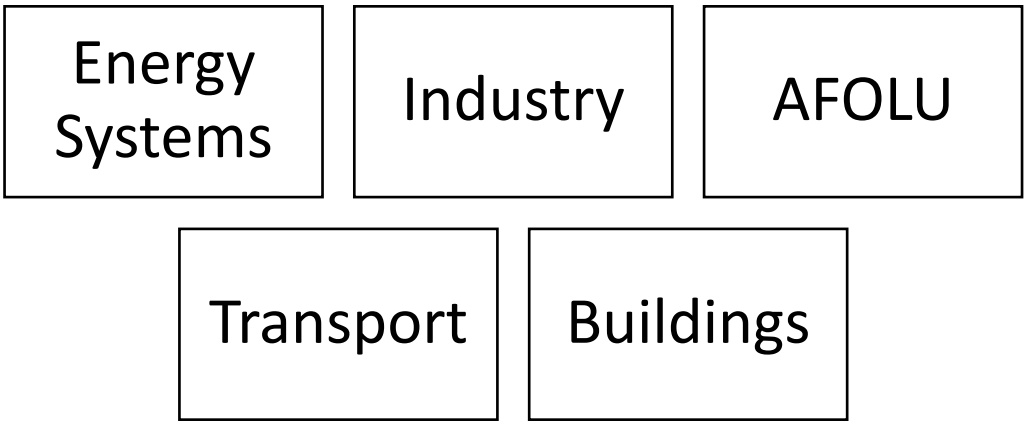

Figure 2.1: Five sectors in which global GHG emissions are calculated.

In 2018, the highest emissions were from the energy systems sector (34%), followed by industry (24%), AFOLU (21%), transport (14%), and buildings operations (6%)(Lamb et al., 2021).

IPCC classification system is structured around five broad sectors. However, when evaluating environmental impacts at the product level, such as a t-shirt or a car, the classification does not capture the extensive variety of product categories and their specific life cycle phases. This broad categorization aggregates emission values across entire sectors, making it difficult to accurately assess the environmental impacts of individual products.

To aim that greenhouse gas concentrations do not have a dangerous impact on the climate; the Kyoto Protocol was signed in 1997 and the Paris Agreement entered into force in 2016. After the binding agreements, countries started to take more consideration of their impact on the environment. This also leads industries to measure their current impact and improve their businesses in a more sustainable way.

The UN defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs(Commission on Environment, 1987). There is a strong connection between sustainability and climate change. Sustainable practices aim to reduce greenhouse gas emissions and mitigate the impacts of climate change, to ensure a healthier planet for future generations.

2.2. Dimensions of Sustainability

Sustainability is defined by three dimensions: environmental, economic, and social. These dimensions are essential when assessing a product, process, or system's sustainability, as every industrialized product impacts these three areas. Consuming or using goods, vehicles, buildings, and even services generates carbon emissions throughout their life cycles. Present-day linear economic models, life cycles span material extraction, production, transportation, usage, and end-of-life disposal. Throughout these stages, materials not only gain economic value but also engage with societal elements, such as the labor force, and are responsible for emissions generation. This lifecycle perspective is crucial in understanding and addressing the broad impact of consumer goods on global sustainability.

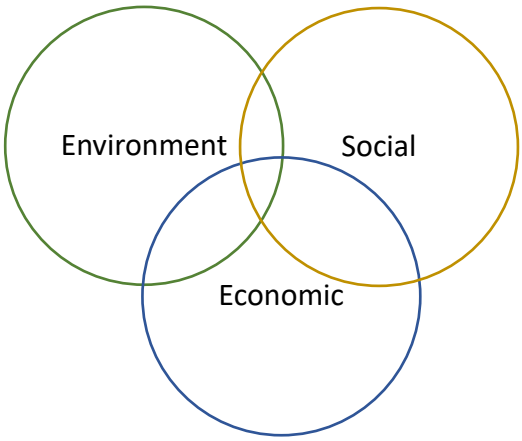

Figure 2.2: Three Dimensions of Sustainability.

Sustainability is applied across various areas, including business practices, urban development, and individual lifestyle choices. Technological innovations in renewable energy, sustainable agriculture, and waste management are also important components.

2.3. Measuring Sustainability

2.3.1. Measuring the Environmental Dimension

Companies assessing their impacts using various tools aligning with regulations. This created a starting point to understand the current impact of their processes. Since each product has different effects on the environment during its life cycle, Life Cycle Assessment (LCA) became an essential tool to measure these effects. "LCA is a tool to assess the potential environmental impacts and resources used throughout a product's life- cycle, i.e., from raw material acquisition, via production and use phases, to waste management" ('ISO', 2006).

An Environmental Product Declaration (EPD) is a transparent, third-party verified report that assesses a product's environmental impact throughout its lifecycle, based on a comprehensive life cycle assessment (LCA) and aligned with the ISO 14025 standard, available publicly('Web 1', 2024a).

In the context of LCA and EPDs, the upstream phase includes raw material extraction and processing, the core phase covers the manufacturing processes within the company, and the downstream phase encompasses distribution, usage, and end-of-life

management of the product. Presented below is an example of the lifecycle phases involved in pasta production, as detailed in an Environmental Product Declaration (EPD)(*Environmental Product Declaration Wheat Pasta in Paperbox.*, 2023).

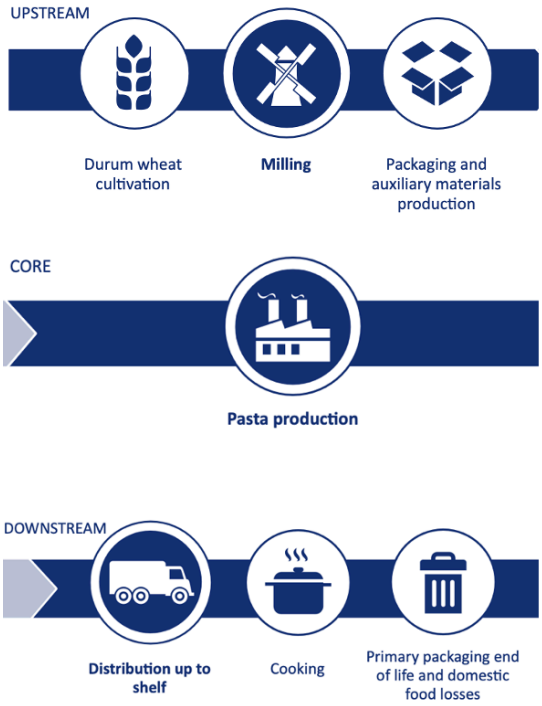

Figure 2.3: Lifecycle Phases of Pasta Production in an Environmental Product Declaration.

An EPD results are measured in the following units: carbon footprint (CO_2e), water deprivation potential (available water remaining per unit of surface), acidification potential (SO_2, NOx, NH_3 emissions), eutrophication potential (phosphates and nitrates emissions), ozone depletion potential (CFC-11), and photochemical ozone creation potential (VOCs). In this thesis, we will utilize Global Warming Potential (GWP) data expressed in kilograms of CO_2 equivalent (kg CO_2e).

EPD outcomes are also consistent with the GRI[1]'s core 15 Environmental Performance Indicators, which include greenhouse gas emissions such as CO2, CH4, N2O, HFCs, PFCs, and related use and emissions (Global Reporting Initiative, 2002).

[1] The Global Reporting Initiative (GRI) is an international organization that provides widely used standards for sustainability reporting, enabling organizations to measure and communicate their environmental, social, and governance (ESG) impacts for greater transparency and accountability.

2.3.2. Measuring the Economic Dimension

The economic dimension of sustainability focuses on ensuring that economic activities are conducted in a way that supports long-term economic health and development while considering the impacts on social and environmental factors.

The core economic performance indicators assess different facets of an organization's economic interactions with its stakeholders and the broader economic systems at local, national, and global levels. According to the GRI, these indicators include: EC1, net sales; EC2, geographic breakdown of markets; EC3, cost of all goods, materials, and services purchased; EC4, the percentage of contracts paid in accordance with agreed terms, excluding penalty arrangements; EC5, total payroll and benefits, broken down by country or region; EC6, distributions to providers of capital, including interest on debt and borrowings, and dividends; EC7, the increase or decrease in retained earnings at the end of the period; EC8, the total sum of taxes of all types paid, broken down by country; EC9, subsidies received, broken down by country or region; EC10, donations to community, civil society, and other groups, broken down into cash and in-kind donations per type of group; EC11, a supplier breakdown by organization and country; EC12, the total spent on non-core business infrastructure development; EC13, the organization's indirect economic impacts; EC14, economic value retained; and EC15, economic value distributed (Global Reporting Initiative, 2002).

In optimization models, the focus is often on minimizing costs or maximizing profit. In this thesis, we will consider price as an economic dimension and aim to reduce it as a cost.

2.3.3. Measuring the Social Dimension

The social dimension, which is the most challenging aspect of measuring sustainability, can be addressed through various parameters. Organizations can demonstrate their commitment to corporate social responsibility (CSR) on a product basis by using various social certifications. Below, you can find examples of these certifications, which are used as labels on products.

Figure 2.4: Social Certificate Examples (logos retrieved from certification websites).

GRI's indicators comprehensively assess an organization's social impacts, focusing on aspects such as labor practices and diversity, with key indicators including workforce breakdown, employment creation and turnover, injury and absentee rates, etc. (Global Reporting Initiative, 2002).

2.4. Sustainable Shopping

Shopping has been searched in marketing, sociology, anthropology, and cultural geography literature (Fuentes, 2014).

Based on an EU survey, %80 of consumers often or sometimes buy environmentally friendly products and %77 of the customers are willing to pay more for an environmentally friendly product(European Commission, 2013). It should be mentioned that the same consumers also do not highly trust on brand's environmental claims. Therefore in transparent environmental product systems, consumers are interested in purchasing green products to lower their effects on climate change and pay for the extra value. Supporting the interaction effect within the sustainability domain will lead consumers to view a company more favorably if it aligns with their support orientations and policies for a specific sustainability area(Choi & Ng, 2011).

When we talked about sustainable purchasing, if we are really aiming to minimize one's effect on the environment, then the unnecessary elements of purchasing should be eliminated. Meaning not buying in the first place. This has been navigated in the literature (Fuentes, 2014), in Fuentes's paper below are practical tools categorized for green purchasing:

1. Shopping for things that will last
2. Buying only what you really need
3. Shopping for green products

This makes green purchasing more of an evaluation process whether than a selection. Do we need this product? Is it durable enough? How can I buy less?

In this thesis, we will focus on the retail sector's sustainable purchasing processes therefore the third option has the most fit in terms of shopping in a market to purchase food. Shopping for green products requires a pre-knowledge of a consumer to determine if the product is environmentally friendly. This could depend on their perception of the brand's values (Fuentes, 2014),or many other parameters affecting the product's life cycle. This brings the question of how do we know. Stöckigt, Schiebener, & Brand suggest that providing a simple explanation equally in each product for of its environmental impact including the manufacturing working conditions and transport would positively affect customers' decision-making, considering extending their budget for the product(2018). O'Rourke & Ringer suggest that within the constraints of online shopping, which includes health, social, and environmental ratings along with product prices, certain types of products are more likely to influence customer behavior (2016).

2.4.1. Sustainability in Retail Sector Focusing on Supermarket Goods

The retail industry is projected to expand from USD 32.68 trillion in 2024 to USD 47.24 trillion by 2029(Mordor Intelligence Research & Advisory, 2024). The sector employs billions of people and represents 31% of the world's GDP(BusinessWire, 2016).

This thesis optimization model addresses the need for individual decision-making tools in sustainable purchasing. We will focus on "needs" because it is the most sustainable criterion for individuals when evaluating purchasing decisions. Moreover, this approach encompasses multiple CO2e-intensive sectors through the simple act of purchasing a single product from a supermarket shelf.

To illustrate, consider a pasta product in terms of its IPCC sector relations and life cycle phases. With a rough evaluation, we can link "energy" systems involved in

milling, production, distribution, cooking, and even in the wheat cultivation phase where agricultural machines are used. The "AFOLU" sector is directly engaged with wheat cultivation. The "Industry" sector is involved in the packaging and production phases. Distribution involves the "Transport" sector. Finally, "Buildings" are involved with industrial spaces and warehouses where the product is stored.

From an economic perspective, each product holds intrinsic value. From a social perspective, these products may have been produced under fair and ethical conditions, with social considerations evaluated at each phase of their life cycle.

3. THE RELATIONSHIP BETWEEN OPTIMIZATION AND SUSTAINABILITY

Sustainability encompasses three primary dimensions: economic, environmental, and social. In optimization models, the economic dimension is often addressed through the minimization of costs or the maximization of profit, as represented in the objective function. Meanwhile, the environmental dimension is incorporated by considering the environmental impact of materials, which is assessed based on Life Cycle Assessment or other available methodologies and integrated into the objective function. The social aspect, on the other hand, is typically included within the constraints of the model.

Mujkić, Qorri, & Kraslawski(2018) conducted a literature search of 50 articles on sustainable supply chain optimization, finding that LP, MILP, NLP, MINLP, GA, FA, and HA optimization models are used in various sustainability aspects, with only 11 of them covering all three aspects of sustainability. Since it is hard to define tangible parameters for the social aspect of sustainability and reach the environmental information of products or services, one of the important outputs from this research was the main objective was cost minimization while other environmental indicators are being used. Below is the list of mostly used sustainability parameters in their literature search:

- Economic: Total costs(32), Profit(7), Cash Flow(6), Delivery lead time(5), Demand uncertainty(5)
- Environmental: CO2 emission(7), Damage to human health(4), GHG emission(4), Damage to eco-system quality(3)
- Social: Jobs created(4), Employment(3), Occupational health and safety(3)

Pamucar & Stevićpublished 25 articles under the concept of OR tools to solve sustainable engineering problems(2022). We observe that topics such as logistics and scheduling have been addressed in multiple articles. MCDM highlights itself to solving various engineering problems including traffic, location selection, and healthcare…

Kumar notes that despite challenges from conflicting criteria and non-comparable functions in multi-criteria problems, it's possible to identify optimal solutions(2020).

A case to summarize the structure of optimization models commonly encountered in the literature. This simplified example of a MILP(Mixed Integer Linear Programming) model can be provided. The model aims to select suppliers and determine the purchase quantities from each supplier for each product, such that the total cost and negative sustainability impacts are minimized, subject to satisfying product demand and not exceeding supplier capacities. The model integrates economic, environmental, and social criteria into the purchasing decision-making process.

Decision Variables:

- x_{ij}: Quantity of product *j* to be purchased from supplier *i.*

  y_i: Binary variable, 1 if supplier *i* is selected, 0 otherwise.

Parameters:

- C_{ij}: Cost of purchasing product *j* from supplier *i*.
- E_{ijk}: Environmental impact of purchasing product *j* from supplier *i* under criterion *k.*
- S_{ijk}: Social impact of purchasing product *j* from supplier *i* under criterion *k*.
- D_j: Demand for product *j*.
- SC_{ijk}Supply capacity of supplier *i* for product *j*.
- W_k: Weight or importance of sustainability criterion *k*.
- T_{jk}: Threshold for the maximum allowable social impact for product *j* under criterion *k*.

Objective Function:

Minimize the total cost and negative environmental impacts: Minimize

$$minZ = \sum_i \sum_j C_{ij} x_{ij} \ + \sum_i \sum_j \sum_k W_k \, E_{ijk} x_{ij}$$

Constraints:

1. Demand Satisfaction: For each product *j*, the sum of quantities purchased from all suppliers must meet the demand.

$$\sum_i x_{ij} \geq D_j \ , \forall j$$

2. Supply Capacity: The quantity of each product jj purchased from each supplier it cannot exceed the supplier's capacity.

$$x_{ij} \leq SC_{ij} y_i \forall i, j$$

3. Supplier Selection: A supplier's capacity can be used only if that supplier is selected. (Where *M* is a sufficiently large number)

$$x_{ij} \leq M_{y_i}, \forall i, j$$

4. Social Impact Constraint: The total social impact for each product and criterion should not exceed a predefined threshold.

$$\sum_i S_{ijk} \, x_{ij} \leq T_{jk}, \forall j, k$$

5. Non-negativity and Integrality:

$$x_{ij} \geq 0, y_i \in \{0,1\}, \forall i, j$$

3.1. Literature in Sustainable Purchasing and Optimization

The procurement literature on sustainable supply chains focuses on the decision-making of companies.

Sustainable purchasing is the key driver in pushing companies to apply sustainable practices in their products's life cycles. In the literature, we mainly see green procurement and/or purchasing decision-making models focused on supplier selection. In time green procurement became an important subject for companies to select their suppliers with environmental considerations. The motivations behind selecting the

greener suppliers can be counted as environmental performance, compliance with environmental regulations, resource efficiency, ethical-social responsibility, innovation, and collaboration (Kumar Sahoo & Shubhra Goswami, 2024).

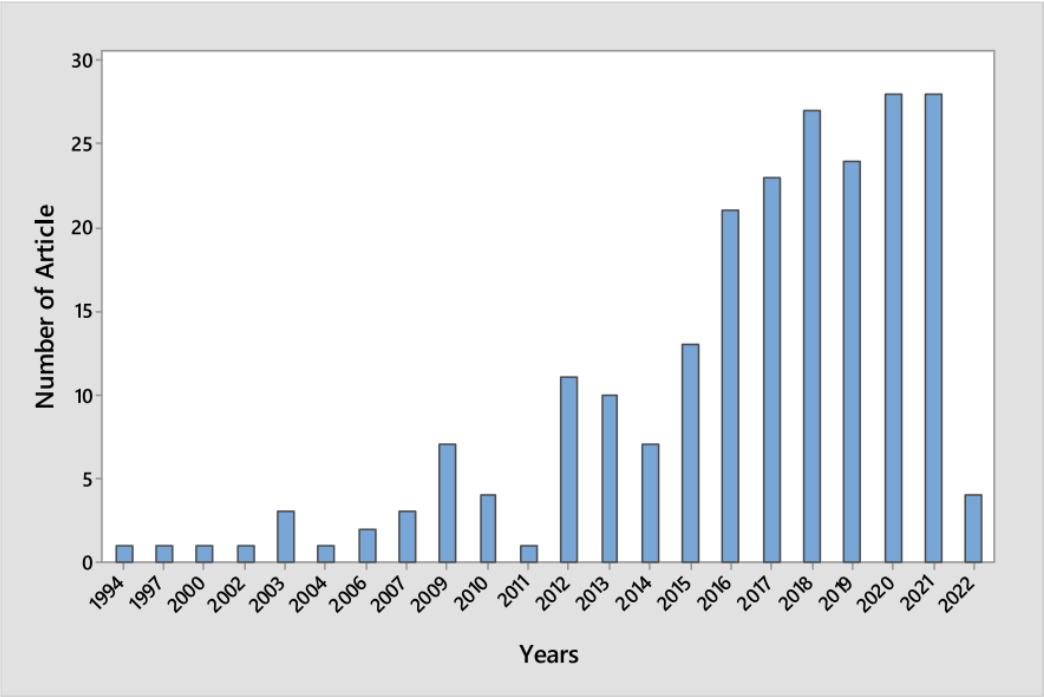

Figure 3.1: Annual Scientific Productions Of Green Procurement Through Supplier Selection (Masudin et al., 2022).

Academic literature reflects the interest of companies in the supply chain in green practices focusing on green procurement. (Masudin, Umamy, Al-Imron, & Restuputri, 2022) published a bibliometric review on Green procurement and implementation through supplier selection and structured literature study sample for the years between 1994–2022. Also can be seen in the graph, the publications increased between 2014 to 2018.

The Industrial Engineering field embraced the subject starting using MCDM tools to select suppliers with environmental considerations. However, the same focus did not continue with the shopping decisions of individuals.

When looking at the decision-making literature on shopping systems (Błażewicz & Musiał, 2011)created an NP-hard mathematical model to solve multi-item internet shopping problems, they developed a Heuristic Algorithm.

Recent studies aiming to optimize consumer activities have varied, encompassing the selection of the best shops for purchasing specific products(Porras & Baruque, 2017) optimization of online shopping (Błazewicz, Kovalyov, Musiał, Urbański, & Wojciechowski, 2010) and the optimization of multi-item shopping lists across various shop locations (Błażewicz & Musiał, 2011).

Research on optimization within consumer activities has primarily concentrated on identifying optimal shops, locations, and similar aspects. However, it has been observed that despite a growing interest among the public in buying more environmentally friendly products, the literature in Operations Research (OR) and Industrial Engineering (IE) has not significantly addressed consumers' decisions when it comes to choosing products.

4. SUSTAINABILITY-DRIVEN CONSUMER CHOICE OPTIMIZATION USING MULTI-OBJECTIVE LINEAR PROGRAMMING

4.1. Problem Definition

The primary objective of this research is to develop a mathematical model that optimizes consumer purchasing decisions in retail shopping, considering both cost and environmental impact. This model aims to fill the gap in existing literature where optimization methods have been extensively applied to sustainable supply chain management but not adequately to individual consumer decisions. Existing research on optimization within consumer activities has primarily focused on identifying optimal shops or locations rather than optimizing product choices based on environmental and cost criteria.

Additionally, there is an increasing public interest in sustainability, driven by greater awareness and more stringent regulations. Consumers are more inclined to buy environmentally friendly products, and regulatory frameworks are pushing for more sustainable practices. This research seeks to bridge the gap by utilizing Multi-Objective Linear Programming (MOLP) to minimize both the cost and environmental impact of products in a consumer's shopping list. The model will integrate real-world data, including EPD-certified products and their respective prices, to provide a practical tool for optimizing retail purchasing decisions. The ultimate goal is to contribute to the academic literature by demonstrating the potential of optimization methods as effective tools for sustainable consumer decision-making.

4.2. Use Case, Model Data and Assumptions

In the use case scnerio of the model is the user has a shopping list (product categories and quantities) and also weights the cost (w1) and environmental impact (w2) for the model. Apart from this, the MOLP model uses the supermarket database as data, where the category, brand/model, volume, cost and environmental impact value of each

product are set. The model uses all this information to present the optimum shopping list to the user as shown below on 4.1.

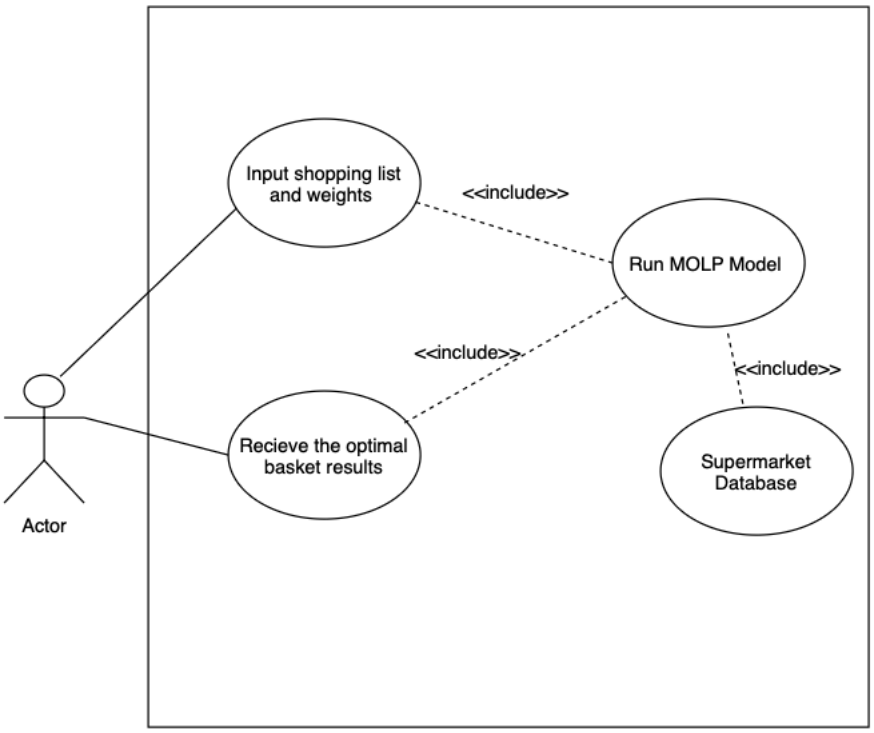

Figure 4.1: Use Case Diagram of the Model.

A dataset representing a shopping list and supermarket database needs to be provided to the model. The model was executed using two datasets: one with realistic data and the other with synthetic data. Initially, realistic data were used, but due to the limited number of products, secondly we introduce a synthetic and fictive dataset designed to explore the interplay between consumer purchasing behavior, and environmental impact in a retail context. For the realistic dataset, the model was provided with three different shopping lists as input.

The first dataset contains realistic values and was created using supermarket products with EPD certificates from the environdec website(‘Web 2’, 2024b). Prices for these products were sourced from various online supermarket sites. Products that had both price and EPD certificates were included in this dataset. The assumptions used while organizing the dataset are as follows:

- The LCA GWP value is written in kg CO2.

- GWP value is generally reported for 1 kg of the product, but adjustments were made according to the package size of the product in the table. For example, the GWP value for a product sold in 500 g packages was divided by two.

- Upon completing the dataset, it was observed that there were products with very different weights. To provide more consistent data to the model, the environmental impact values were also scaled, and product information was standardized. For instance, a 380 g product was calculated as a 500 g product, and the environmental impact value was recalculated accordingly. This allowed multiple product alternatives to be created for a single product category choice.

One notable observation during the creation of this dataset was that the supermarket products in the EPD database were predominantly from Italian companies.

4.3. Model Development

The mathematical model is designed to optimize individuals' purchasing decisions in retail shopping, focusing on two main criteria: cost and environmental impact. This optimization is formulated using the Multi-Objective Linear Programming (MOLP) approach. This approach is suitable for balancing multiple, often conflicting, objectives.

Variables and Parameters:

Product Categories I: Such as milk, bread, eggs. Each i is represented within I.

Brand and Model K_i : All models under each product category i are represented within K_i . Each model is uniquely defined by its brand, size, and other specific attributes.

Price C_{ik}: The price of model k in category i.

Environmental Impact e_{ik}: The environmental impact of model k in category i.

Decision Variable x_{ik}: If model k from category i is selected, the amount purchased is x_{ik}. This value is an integer.

Objective Fuction:

$$minZ = w1 \sum_{i \in I} \sum_{k \in K_i} c_{ik}\, x_{ik} \; + w2 \sum_{i \in I} \sum_{k \in K_i} e_{ik}\, x_{ik}$$

Constraints:

Ensuring Minimum Quantity for Each Product Category:

$$\sum_{k \in K_i} v_{ik}\, x_{ik} \; \geq \; M_i, \forall i \; \in \; I$$

Here, where v_{ik} represents the volume or quantity of product k in category i ; M_i is the minimum required quantity for the product category

Integer Constraints for Decision Variables:

$$x_{ik} \; \geq \; 0, \forall i \; \in \; I, \forall k \; \in \; K_i$$

x_{ik} must be an integer.

Weight Relationship:

$$w1 \; = \; 1 - \; w2$$

$$w1, w2 \; \in \; [0,1]$$

In this specific model, the decision variable x_{ik}: represent the quantity of model k selected from product category i. These decision variables are integers, reflecting the actual number of products to be purchased. The objective function is the weighted sum of total cost and total environmental impact, where C_{ik} denotes the cost of selecting model k from product category i, and eik denotes its environmental impact. The weights $w1$ and $w2$ allow the decision-maker to prioritize between cost and environmental considerations, adjusting the sensitivity of the model to price and environmental footprint.

The constraints in this model ensure that operational and supply requirements are met in alignment with sustainability goals. The first group of constraints guarantees the selection of a sufficient quantity from each product category, where v_{ik} represents the volume or quantity of product k in category i, and M_i represents the minimum required quantity for category i. This constraint ensures that operational demands are met for

each product category. Additionally, the model enforces that the decision variables x_{ik} are non-negative and integer, ensuring that the solutions are practical and applicable in a real-world retail setting. The weight relationship constraint ensures that $w1$ and $w2$ sum to 1, indicating that increasing the importance of one criterion decreases the importance of the other.

4.4. Realistic Data Model Solution and Results

The mathematical model has been coded in the Python environment, with scaling performed due to the environmental impact and product price being in different units. Additionally, the following libraries were used in the execution of the code: NumPy, PuLP, Matplotlib, and Pandas.

The use case of the model represented as utilizing one individual's decision making process on one shopping list. However, to see the trade-of between environmental impact and cost, the model did not used only one weight option, but hundreds.

Three shopping lists were created using realistic data, maintaining the same product categories but varying their quantities.

The Pareto diagrams in Figure 4.2, 4.3 and 4.4 are a graphical representation of the trade-offs between two competing objectives: Total Cost (€) and Total Environmental Impact (kg CO2-equivalent). This diagram is a visual tool that helps in understanding the relationship between these two objectives and how changes in weighting (w1 for cost and w2 for environmental impact) affect the optimization results.

The curve represents the Pareto efficient frontier, which consists of solutions where no objective can be improved without worsening the other. This indicates that all points on this frontier are optimal solutions given the trade-offs between cost and environmental impact.

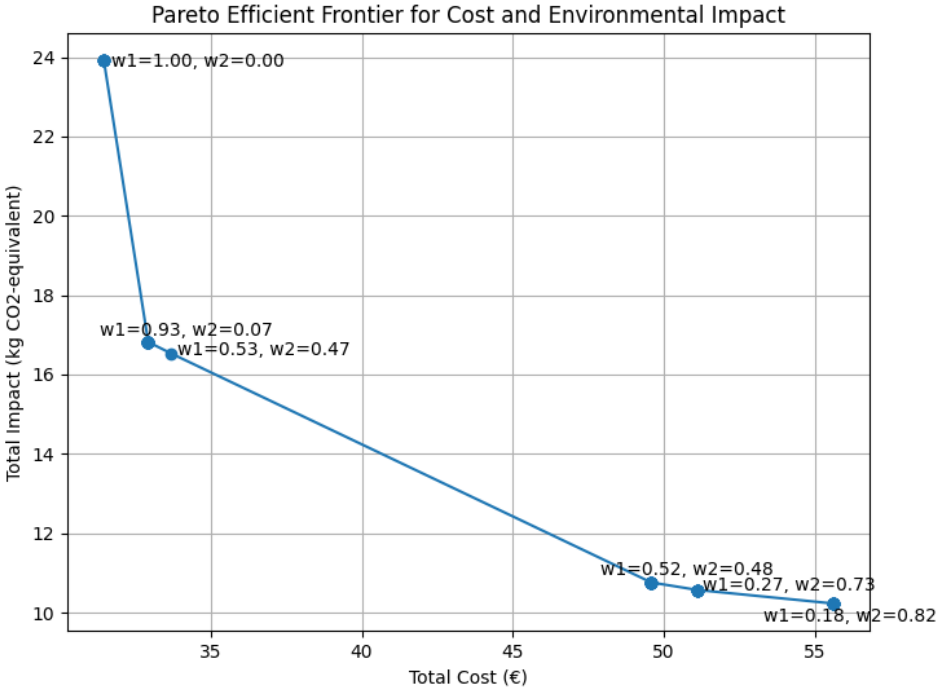

Figure 4.2: Shopping List 1, Realistic Data MOLP Pareto Results.

The Pareto diagram and the detailed shopping choices at different weight values demonstrate the trade-offs between cost and environmental impact in consumer purchasing decisions. The breakpoints reflect critical regions where significant shifts in priorities occur. This analysis can guide consumers in making informed decisions that align with their sustainability goals and budget constraints.

In the analysis of cost and environmental impact, we observed that even slight changes in the weights assigned to these criteria can lead to significant variations in the results. The analysis reveals that slight variations in the weights assigned to cost and environmental criteria, such as a change from w_1=0.52 to w_1=0.53, can lead to substantial differences in outcomes. Specifically, this slight adjustment only involves a single product change, but it leads to noticeable changes in the overall impact and cost. This indicates that despite the proximity of the weight values, dealing with discrete data causes the results to vary significantly.

Adding to this discussion, the extreme orientations with respect to cost and environment demonstrate a wide range in terms of environmental outcomes. An entirely cost-oriented approach can incur costs as low as 32 euros for the bundle, at an environmental burden of 24 kgs CO_2 equivalent. Conversely, a focus purely on environmental concerns without budget constraints can lead to costs exceeding 55€, while significantly reducing the environmental impact to around 10 kg CO_2 equivalent. This range is illustrated by the convex structure of the trade-off curve, highlighting that consumers do not have to adhere to extremes to find value.

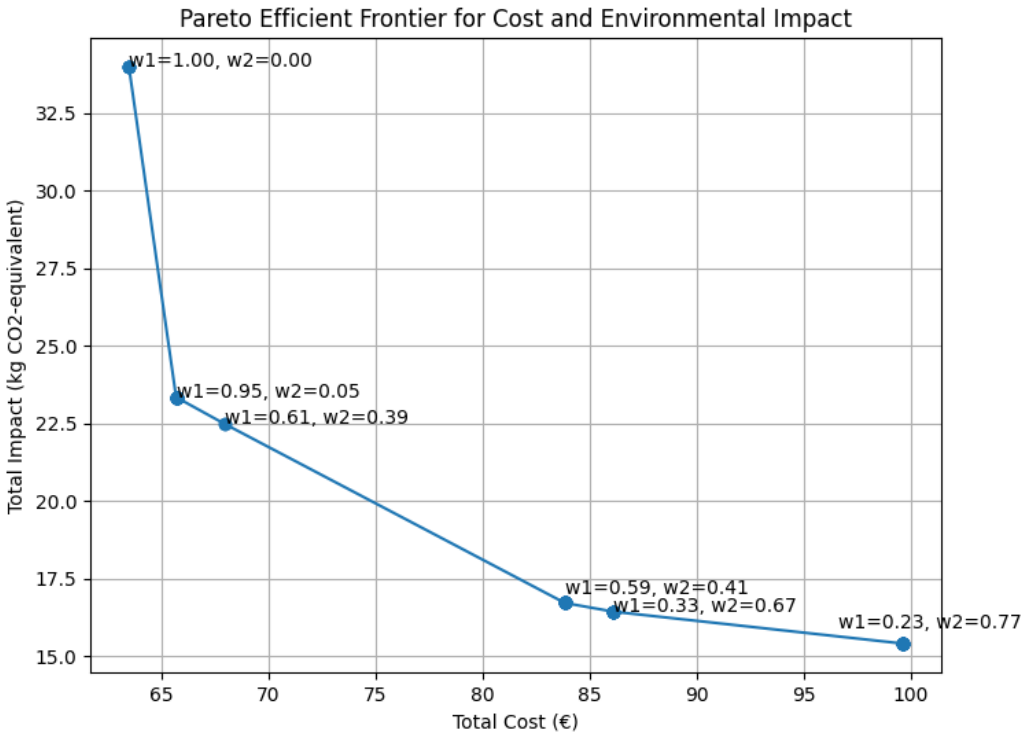

Figure 4.3: Shopping List 2, Realistic Data MOLP Pareto Results.

The trade-off relation between cost and environmental impact in the 2nd shopping list is similar to the first list. The analysis reveals that slight variations in the weights assigned to cost and environmental criteria, such as a change from w1=0.61 to w1=0.59, can lead to substantial differences in outcomes.

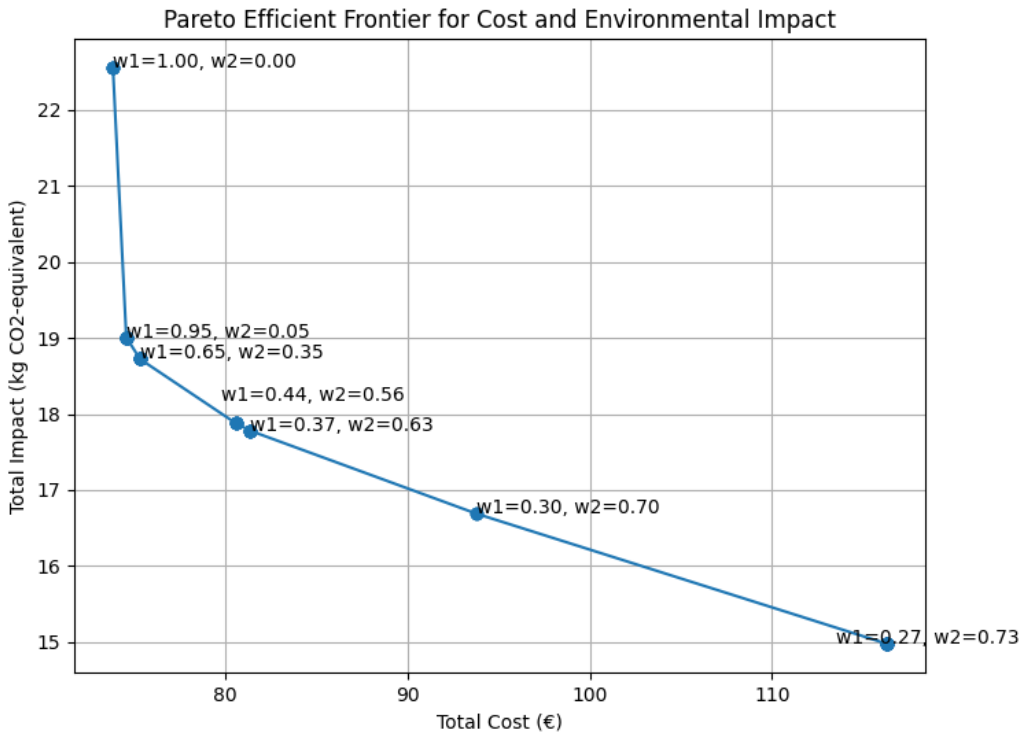

Figure 4.4: Shopping List 3, Realistic Data MOLP Pareto Results.

Shopping List 3 results are different from the first 2 lists. We observe that at lower basket values, the user's weighting importance does not significantly affect the outcomes. The nearly one-third difference between w1:0.95 and w1:0.37 translates to only a 9% and 6% impact on cost and environmental impact. Specifically, on the environmental side, if a shopping experience with a lower environmental impact is desired, the importance given to cost must be greatly reduced, leading to a substantial increase in basket value.

In this thesis, it was observed that informing users about not only their specific preferred ranges but also the nearby ranges is crucial. This approach, highlighted by the Pareto analysis, ensures that users are aware of the potential impacts of slight adjustments in their preferences.

4.5. Modeling Societal Orientations and Outcomes

In this section, we introduce a synthetic and fictive dataset designed to explore the interplay between consumer purchasing behavior, cost, and environmental impact in a

retail context. The dataset encompasses 277 products spanning 59 distinct product categories. Each product is characterized by specific attributes, including the quantity in its respective unit, a price tag, and an environmental impact label that considers the burden from supply, production, to market shelf.

Each product category is purchased by retail shoppers with a certain probability. If a purchase occurs, the amount the shopper desires to buy follows a lognormal distribution with a known mean and standard deviation (Table 4.1). This approach allows for the modeling of realistic purchase quantities and reflects the variability observed in actual consumer behavior. Table 4.1 represents the sample rows from the synthetic dataset. Probability of purchase from each category in a shopping list, mean and standard deviations of purchased amount if the product purchased.

Product Category	Purchase Probability	Mean	Standard Deviation	Unit
Baby Foods	30	130	40	g
Baked Goods	48	340	75	g
Baking Supplies	34	395	225	g
Juice	11	1000	500	ml

Table 4.1: Sample rows from the synthetic dataset of product categories.

To capture the diversity in societal orientations towards environmental concerns and sustainability consciousness, we consider seven distinct societal orientations. These orientations are represented by a distribution of customer types, indicating an individual's inclination towards being cost-oriented or environmentally oriented. This inclination is quantified by the parameters w_1 and w_2 in the optimization model described by equations (1)-(3) in Section 3.2.

It is important to note that this synthetic dataset is entirely fictive and is not derived from real product or sustainability databases. The aim is to provide a robust framework for analyzing the potential impacts of different consumer orientations on overall cost and environmental outcomes in a retail setting.

These societal orientations are represented by Beta distributions, which take values in the interval (0, 1). The Beta family encompasses a wide range of distribution shapes, from highly right-skewed distributions that are asymptotic to x=0 (indicating a heavy accumulation at low values) to milder right-skewed distributions, symmetric distributions with varying levels of deviation from the mean 1/2, and left-skewed distributions with high accumulation at high values. The choices for shape parameters α and β of these Beta distributions are provided in Table 4.2.

Distribution	α	β
Beta 1	10.0	90.0
Beta 2	6.0	24.0
Beta 3	4.5	10.5
Beta 4	2.5	2.5
Beta 5	10.5	4.5
Beta 6	24.0	6.0
Beta 7	90.0	10.0

Table 4.2: Distributions modeling the societal orientation towards weighing economic and environmental aspects.

The distribution parameters α and β in Table 4.2 highlights the diversity of societal orientations, representing societies ranging from those extremely environmentally-oriented with minimal regard for cost (low w_1 values) to those at the opposite extreme, which prioritize cost over environmental concerns (high w_1 values). Although these extreme orientations may not be the norm, the economic orientation is more prevalent and dominant in many societies. The symmetric distribution Beta (2.5, 2.5) represents a balanced societal orientation towards both economic and environmental concerns. The two distributions on each side of this balanced distribution reflect varying degrees of shift towards sustainability or economic ends.

As environmental awareness, education, and concerns about sustainability increase, there is hope for a societal shift towards the environmentally oriented society

represented by the most right-skewed distribution Beta (10.0, 90.0). Figure 4.5 illustrates the probability density functions (PDFs) of the selected Beta distributions.

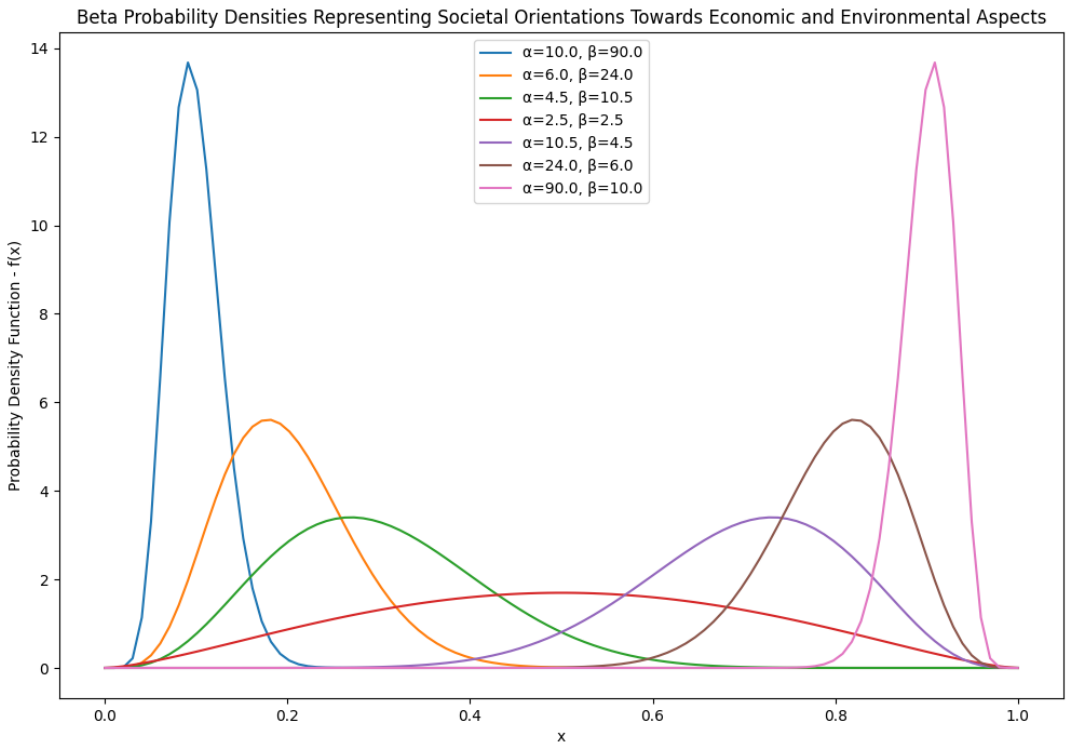

Figure 4.5: The distributions from Beta family defining the societal disposition towards economic (w_1=x) versus environmental (w_2=1-x) concerns.

For each distribution, a customer sampled has a type parameter randomly chosen from the distribution ($w_1 \sim Beta(\alpha_i, \beta_i)$, $i = 1, \ldots, 7$), decides whether to purchase from a product category according to the probabilities as exampled in Table 4.2, and if so, the amount is sampled from the respective distribution for the product category. Weighing cost and environmental impact components in (1) according to her/his type w_1, the customer chooses an optimal bundle according to the model (1)-(3) discussed in Section 3.3. Table 4.3 displays the mean and standard deviations of the cost and environmental impacts of bundles purchased by 10000 customer samples from each of the distributions defined above. Additionally, the table displays the mean and standard deviations of the cost and environmental impact outcomes when all samples are pooled together, considering three cases: the individuals form entirely cost oriented bundles (assuming $w_1 = 1$ for all), they form entirely environmentally concerned bundles (assuming $w_1 = 0$ for all), or they purchase according to their own types (w_1 as sampled from respective distributions).

Population	Cost		Impact	
	Mean	Stdev	Mean	Stdev
Overall*, Cost Minimizer	35	12.4	10.2	4.4
Overall, Impact Minimizer	44	15.1	9.2	4
Overall, Weighted	36.6	12.9	9.6	4.1
Beta 1, Weighted	39.3	13.5	9.2	3.9
Beta 2, Weighted	37.9	13.3	9.3	4
Beta 3, Weighted	37.1	12.9	9.4	4
Beta 4, Weighted	36.1	12.6	9.6	4.1
Beta 5, Weighted	35.4	12.4	9.9	4.2
Beta 6, Weighted	35.1	12.4	9.9	4.2
Beta 7, Weighted	35	12.5	10	4.2

Table 4.3: Comparative analysis of cost and environmental impact statistics for different societal dispositions.

*Overall: Customer shopping lists pooling samples from all 7 distributions. Cost minimizer: (1)-(3) is solved for each customer assuming $w_1 = 1$ (sample size n = 70000). Impact minimizer: (1)-(3) is solved for each customer assuming $w_1 = 0$ (sample size n = 70000). Weighted: (1)-(3) is solved with w_1 as sampled from the indicated distribution (Beta 1,…7) (sample size n = 10000 for each) or the pool of samples from Beta 1,…,7 (sample size n = 70000). Stdev: standard deviation.

The sample means for cost ranges in 35.0-44.0, as set by the cost minimizing and entirely environmentally concerned ends. Impact changes inversely, with a range 9.2-10.2. Note that these figures are similar when computed for only one of the samples, as the samples are sufficiently large, and they are practically from the same shopping list sampling when weights are overridden to represent the two ends ($w_1 = 0$ or $w_1 = 1$). The cost range is approximately 23% of its scale, and impact range corresponds to 10% for this particular fictive dataset. This is clearly due to the opportunity to save significantly with small difference in environmental impacts, when the customer perspective slightly shifts to incorporate economic concern besides environmental

concern (Figure 4.6, comparing overall cost minimizer to Beta 1). Considering from the opposite end, the economically next best in each category saves a moderate 2% in impacts with slight increase in the cost of the bundle (Figure 4.6, comparing overall impact minimizer to Beta 7). For different societal dispositions regarding economic and environmental orientation, mean bundle cost and impact indicates a convex pattern (Figure 4.6), thus balancing economic and environmental concerns, it is possible to achieve significant proportions of maximum attainable savings in both aspects.

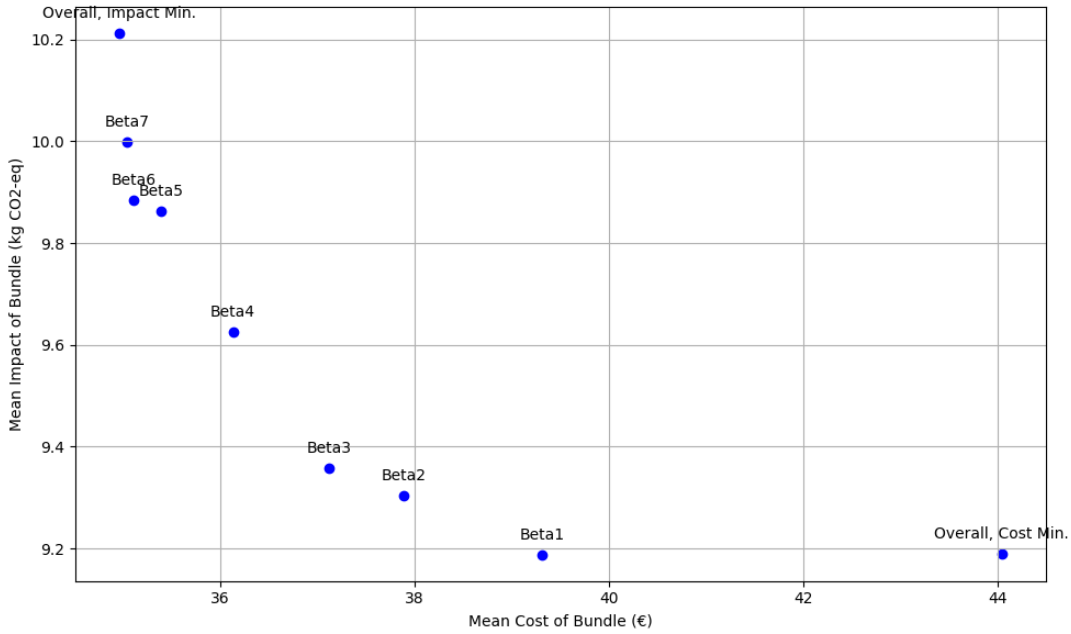

Figure 4.6: Mean cost and environmental impacts of bundles purchased according to entirely economic or environmentally oriented customers, and customers whose weight types are sampled from distributions Beta 1, …, Beta 7.

On considering the shift in the distribution of the cost and environmental impact of bundles for sampled customers, a similar pattern to that emerging in sample means is observed. The most drastic shift, accompanying the shift in mean, occurs between the totally environmentally oriented sample and the one sampled from Beta 1, where slight cost prioritization is introduced alongside the environmental perspective (Figure 4.7, left). Further prioritization of the cost perspective in society does not yield as significant savings per the distribution of the cost of the bundle. The environmental impact histograms on the right-hand side indicate smaller shifts in distribution with changes in societal orientation. However, in compliance with the convex pattern (Figure 4.6), they oppose the cost histograms in direction. Where cost distributions

visibly shift leftwards, as seen in the shift from a totally environmental orientation to Beta 1, impact distributions slightly shift to the right. Relatively larger shifts in the increasing direction occur for impact distribution as the cost orientation in society becomes more pronounced (Figure 4.7, right).

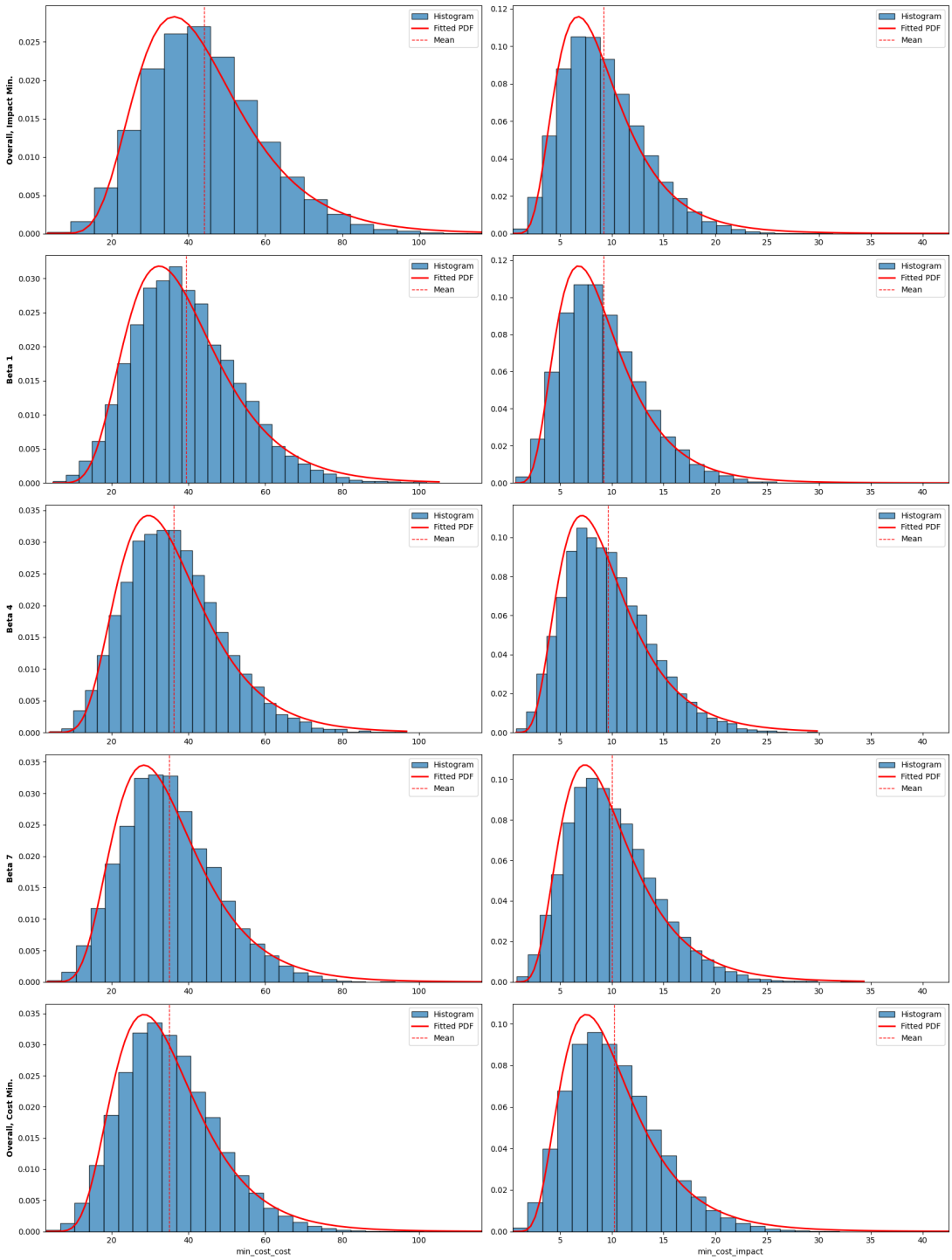

Figure 4.7: Histograms for cost (left) and impact (right) distributions for optimal bundles of overall impact minimizing, Beta 1, Beta 4, Beta 7, and overall cost minimizing samples. Lognormal distribution is fitted on top of probability histograms for visibility of the shift of distributions.

Overall, a 10% reduction in environmental impact is achieved when society shifts to a fully environmentally concerned orientation, which incurs a 23% higher economic burden 9€ per bundle on average. However, 60% of this reduction is accomplished

with only a 1.1€ (3.1%) increase in the cost of an average bundle when society maintains a balanced disposition regarding cost and environmental impact (Beta 4). The product choice-dependent environmental preservation range is 80% achieved with a 2.1€ (6%) increase in mean bundle expense (Beta 3). A society prioritizing the environment over cost almost fully attains the impact reduction by paying 4.3€ (12%) more on the grocery shopping bundle on average. This demonstrates the importance of education and awareness campaigns, highlighting how societal environmental awareness can significantly reduce impacts with relatively small increases in expense when such awareness exists.

This analysis demonstrates the utility of the devised multi-objective customer choice model in capturing and the nuanced interplay between economic and environmental considerations in consumer decision-making. The synthetic dataset allows for a robust examination of how different societal orientations, represented by various Beta distributions, impact overall cost and environmental outcomes in retail purchasing. The analysis reveals that even slight shifts towards environmental consciousness can yield substantial reductions in environmental impact with minimal additional costs. This finding emphasizes the critical role of public education and awareness campaigns in fostering more sustainable consumer behaviors. By understanding these dynamics, policymakers and businesses can better strategize to balance economic growth with environmental stewardship, ultimately contributing to more sustainable societies.

5. CONCLUSIONS

The research presented in this thesis successfully develops a multi-objective linear programming (MOLP) model to optimize consumer purchasing decisions in retail shopping, focusing on both cost and environmental impact. This model addresses a significant gap in existing literature by applying optimization techniques not just to sustainable supply chain management but also to individual consumer decisions. By integrating real-world data, including Environmental Product Declarations (EPD) and product prices, the model provides a practical tool for consumers to make informed, sustainable purchasing decisions.

The analysis demonstrates that even minor changes in the weights assigned to cost and environmental impact can lead to significant variations in the outcomes. This sensitivity highlights the importance of considering a range of weight values to provide consumers with comprehensive information about the potential impacts of their preferences.

A recurring challenge noted during the study was the limited access to comprehensive environmental impact data for products commonly available in supermarkets. Enhanced access to EPD documents and LCA results would enable more refined analyses and improve the model's utility.

The Pareto diagram has proven instrumental in illustrating the trade-offs between cost and environmental impact, directing consumers towards decisions that satisfy both their sustainability objectives and budget constraints. This conclusion underscores the potent role of optimization methods in fostering sustainable consumer behavior and adds valuable insights to scholarly discussions on sustainable decision-making. With broader dissemination of supportive data to both the public and academic spheres, further detailed examination and refinement of these models could ensue, potentially leading to widespread adoption and implementation in various consumer contexts.

By simulating different societal orientations using Beta distributions, an analysis with a fictive dataset demonstrates that even slight shifts towards environmental consciousness can yield substantial reductions in environmental impact with minimal

additional costs. This finding emphasizes the critical role of public education and awareness campaigns in fostering more sustainable consumer behaviors.

REFERENCES

Arrhenius, S. (1896). *On the influence of carbonic acid in the air upon the temperature of the ground*.

Błazewicz, J., Kovalyov, M., Musiał, J., Urbański, A., & Wojciechowski, A. (2010). Internet shopping optimization problem. *International Journal of Applied Mathematics and Computer Science*, *20*(2), 385–390. https://doi.org/10.2478/v10006-010-0028-0

Błażewicz, J., & Musiał, J. (2011). *E-Commerce Evaluation – Multi-Item Internet Shopping. Optimization and Heuristic Algorithms*. https://doi.org/10.1007/978-3-642-20009-0_24

BusinessWire. (2016). *Global Retail Industry Worth USD 28 Trillion by 2019-Analysis, Technologies & Forecasts Report 2016-2019-Research and Markets.* Retrieved from https://www.businesswire.com/news/home/20160630005551/en/Global-Retail-Industry-Worth-USD-28-Trillion

Choi, S., & Ng, A. (2011). Environmental and Economic Dimensions of Sustainability and Price Effects on Consumer Responses. *Journal of Business Ethics*, *104*(2), 269–282. https://doi.org/10.1007/s10551-011-0908-8

Commission on Environment, W. (1987). *Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development 2. Part II. Common Challenges Population and Human Resources 4*.

Environmental Product Declaration Wheat Pasta in Paperbox. (2023). Retrieved from https://www.environdec.com/library/epd7704

European Commission. (2013, July). Attitudes of Europeans towards building the single market for green products. Retrieved 18 February 2024, from https://europa.eu/eurobarometer/surveys/detail/1048

Fuentes, C. (2014). Managing green complexities: Consumers' strategies and techniques for greener shopping. *International Journal of Consumer Studies*, *38*(5), 485–492. https://doi.org/10.1111/ijcs.12124

Global Reporting Initiative. (2002). *GRI Sustainability Reporting Guidelines 2002*.

ISO. (2006). Retrieved 9 January 2024, from https://www.iso.org/obp/ui/en/#iso:std:iso:14040:ed-2:v1:en

Kumar, M. (2020). *Application of Operational Research in Sustainable Environmental Management and Climate Change*. Retrieved from www.econstor.eu

Kumar Sahoo, S., & Shubhra Goswami, S. (2024). Spectrum of Engineering and Management Sciences Journal homepage: www.sems-journal.org Green Supplier Selection using MCDM: A Comprehensive Review of Recent Studies. *Spectrum of Engineering and Management Sciences*, *2*, 1–16. https://doi.org/10.31181/sems1120241a

Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., … Minx, J. (2021, July 1). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters*, Vol. 16. IOP Publishing Ltd. https://doi.org/10.1088/1748-9326/abee4e

Masudin, I., Umamy, S. Z., Al-Imron, C. N., & Restuputri, D. P. (2022). Green procurement implementation through supplier selection: A bibliometric review. *Cogent Engineering*, *9*(1). https://doi.org/10.1080/23311916.2022.2119686

Mordor Intelligence Research & Advisory. (2024). *Retail Industry Size & Share Analysis - Growth Trends & Forecasts (2024 - 2029)*. Retrieved from https://www.mordorintelligence.com/industry-reports/retail-industry

Mujkić, Z., Qorri, A., & Kraslawski, A. (2018). Sustainability and Optimization of Supply Chains: a Literature Review. *OPERATIONS AND SUPPLY CHAIN MANAGEMENT*, *11*(4), 186–199. Retrieved from http://www.sciencedirect.com

O'Rourke, D., & Ringer, A. (2016). The Impact of Sustainability Information on Consumer Decision Making. *Journal of Industrial Ecology*, *20*(4), 882–892. https://doi.org/10.1111/jiec.12310

Pamucar, D., & Stević, Ž. (2022). *Operational Research Tools for Solving Sustainable Engineering Problems*. Retrieved from www.mdpi.com/journal/sustainability

Porras, S., & Baruque, B. (2017). A Hybrid Method for Optimizing Shopping Lists Oriented to Retail Store Costumers. In M. Graña, J. M. López-Guede, O. Etxaniz, Á. Herrero, H. Quintián, & E. Corchado (Eds.), *International Joint Conference SOCO'16-CISIS'16-ICEUTE'16* (pp. 95–104). Cham: Springer International Publishing.

Stöckigt, G., Schiebener, J., & Brand, M. (2018). Providing sustainability information in shopping situations contributes to sustainable decision making: An empirical study with choice-based conjoint analyses. *Journal of Retailing and Consumer Services*, *43*, 188–199. https://doi.org/10.1016/j.jretconser.2018.03.018

Web 1. (2024a). Retrieved 25 June 2024, from https://environdec.com/

Web 2. (2024b). Retrieved 22 June 2024, from Web 2 website: https://environdec.com/library

BIOGRAPHY

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PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

APPENDIX-A: PRESENTATIONS FROM THE THESIS

Tüsün Sapan, B. S. (2024, April 27-28). Optimizing Consumer Choices Through Multi-Objective Linear Programming: Balancing Environmental Impact and Cost. Oral presentation at the 2nd International Interdisciplinary Congress of Women in Science, Sivas, Türkiye. Organized by Sivas Science and Technology University, Baku Eurasia University, Women in Science Association & IKSAD Institute.