UNIVERSITY OF MACEDONIA

MSc in APPLIED INFORMATICS

DIRECTION OF BUSINESS COMPUTING

SOLVING A CAPACITATED FACILITY LOCATION PROBLEM, USING THE WEIGHTED GOAL PROGRAMMING METHODOLOGY.

Master's Thesis

By

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Thessaloniki, February 2024

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Οικονόμου Βασίλειος
Πτυχίο Οικονομικών Επιστημών, ΑΠΘ, 2023

Διπλωματική Εργασία

υποβαλλόμενη για τη μερική εκπλήρωση των απαιτήσεων του

ΜΕΤΑΠΤΥΧΙΑΚΟΥ ΤΙΤΛΟΥ ΣΠΟΥΔΩΝ ΣΤΗΝ ΕΦΑΡΜΟΣΜΕΝΗ ΠΛΗΡΟΦΟΡΙΚΗ

Επιβλέπων Καθηγητή
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Εγκρίθηκε από την τριμελή εξεταστική επιτροπή την ηη/μμ/εεεε

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Οικονόμου Βασίλειος

Abstract

Compared to the past, companies have significantly changed their strategies regarding the location of their facilities to optimize their activities. Specifically, the numerous factors related to this fact include the geographical position of a network's stakeholders, like suppliers and consumers, the availability and cost of the labor force, the various legislative factors like trade agreements and tax policies, and the minimization of CO_2 emissions. In the present thesis, a weighted goal programming model is proposed to study the capacitated facility location problem of a reverse supply chain. Specifically, to determine the optimal position for the installation of remanufacturing centers, the model aims at the simultaneous minimization of the deviations of the total cost and total carbon dioxide (CO_2) emissions from a set of predetermined goals. Regarding the practical implementation of the model, we apply it to a reverse logistics network of ink and toner cartridges in Thessaly, Greece. In more detail, to indicate the optimal strategy for the reverse network, given its fifteen installed collection points in combination with five locations for the installation of remanufacturing centers, we implement an objective function that takes into consideration the transportation costs, the installation costs, and the CO_2 emissions as its variables. Finally, the above procedure is applied using Excel Solver, concluding with a sensitivity analysis that indicates all the optimal strategies according to the changes in the weights of the cost and emission factors.

Keywords: Capacitated Facility Location Problem, CO_2 Emissions, Cost, Reverse Supply Chain Optimization, Weighted Goal Programming

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List of Abbreviations

CF: Capacitated Facility

CLSC: Closed Loop Supply Chain

CSC: Circular Supply Chain

DLB: Disassembly Line Balancing

DSP: Disassembly Sequence Planning

EOL: End of Life

EOU: End of Use

ESG: Economical Social Governance

FL: Facility Location

GP: Goal Programming

KPI: Key Performance Index

LGP: Lexicographic Goal Programming

LH: Long Haul

MILP: Mixed Integer Linear Programming

OEM: Original Equipment Manufacturer

QOS: Quality of Service

RL: Reverse Logistics

RSC: Reverse Supply Chain

SC: Supply Chain

UCF: Uncapacitated Facility

VRP: Vehicle Routing Problem

WGP: Weighted Goal Programming

1. Introduction

1.1 Reverse Logistics Overview

Sustainability is one of the most important and biggest unresolved problems that plague modern society, the resolution of which has the potential to bring us enormous benefits. In addition, sustainable or green development can become the solution to various and complex issues in the modern world, regarding both technological, social, and legislative factors. Minimization of the environmental damage that the generation of enormous amounts of waste causes, maximization of the waste's value recovery, and general enhancement of product reuse are some of the major goals that sustainable development is trying to achieve [121]. In the last few years, waste management has concentrated all the research interest on two main branches: source reuse and environmental protection. Reverse logistics can achieve the above objectives because, in them, the value of materials and resources remains within the economic circuit for the maximum time possible [125]. Due to the shift towards the circular economy, there has recently been a sharp increase in the re-circulation of materials, components, and products through various recovery routes. In this case, the exploitation of the RL framework is considered by various organizations as a necessary condition for their optimal operation. However, special attention should be given to this matter due to the complex nature of RL and its various areas of application, which differ significantly from forward or traditional distribution channels [79].

1.1.1 Definition

In terms of its definition, reverse logistics can be described as the management of a product's retrieval efficiently and effectively to either recover its remaining value or dispose of it. In a more generic framework, the circular supply chain (CSC), which includes both forward and backward logistics, describes the value creation from reducing, reusing, and recycling natural resources [79]. Complementary a reverse network constitutes the study of EOL and EOU products from the customers. Beyond that, reverse SC can be translated as efficient and effective material flow control for active inventory, finished goods, and all the related information from the consumption point to the source for the sole purpose of retrieving its residual value [125]. A reverse supply chain is a set of activities for the recovery of a product at the end of its life from the consumer with the aim of recycling, remanufacturing, or destruction [6]. Additionally, it strives to maximize the reuse of EOL products via remanufacturing processes, giving them the same quality and functionality as if they were new [96]. Another term that is frequently used refers to the process of disposal and value recovery for EOU products. “The transportation cycle from the consumer to the producer," “the repositioning of materials back to the manufacturer," and “the conversion of unusable products to ones that are once again requested from the public" are some of the main concepts that define a reverse distribution channel [136]. Summing up, all different definitions can be concentrated on the following: “the total activities associated with a post-sale service or product that aim to maximize aftermarket efficiency, thus saving both natural and economic resources." [136], based on the term given to RSC by the Reverse Logistics Association (RLA).

1.1.2 RL Network Structure

The first stage in the design process of an RL network presupposes the determination of its structure. Specifically, this entails defining the basic elements of the network as well as the different relationships that play out between them. A RL network consists of four structural elements or stages: first, the production centers, where the initial products are manufactured. The second stage consists of the various collection centers, which gather used products from customers. Also, at this stage, used products are subject to inspection and disassembly. The next stage includes the control of the returned products and resources, to decide their further utilization or destruction. The last stage involves the consumer markets, where the new products are returned for reuse [138]. Figure 1 describes the process that we just mentioned above. The collection center gathers all returned products from consumers. Then, these products are inspected, and a selection is made of those that will be discarded or will be further utilized (reused, recycled, remanufactured, cannibalized). Finally, all new products are dispersed back onto the market, to add extra value to the whole economic system. It must be pointed out that all remanufactured products are sold on secondary markets [96]. Kamran et al. [92] previously analyzed the same process. Precisely, they described it “as a system that shows the material flow or product return rate, from the customer zone to collection and inspection centers, for the final decision of guidance to either recovery or disposal facilities."

The emergence of ESG policies in recent years, as well as the general trend for environmental protection and eco-friendly consciousness that prevails, has led the various legislative mechanisms of various countries to the institution of compliance regulations to limit the eco-damaging actions of producers as well as to expand their responsibility. Given the regulatory enactment and the enormous economic benefits that can be brought about by the adoption of ESG policies, the market has begun to integrate the management of reverse networks into business activities, thus creating a closed system (CLSC) that may prove vital for the environment. The EOU products are returned from the consumer back to the manufacturer, and through a process of selective remanufacturing, they are forwarded again to a new supply chain. In CLSC, the terminals of both forward and reverse networks are in the same group [96].

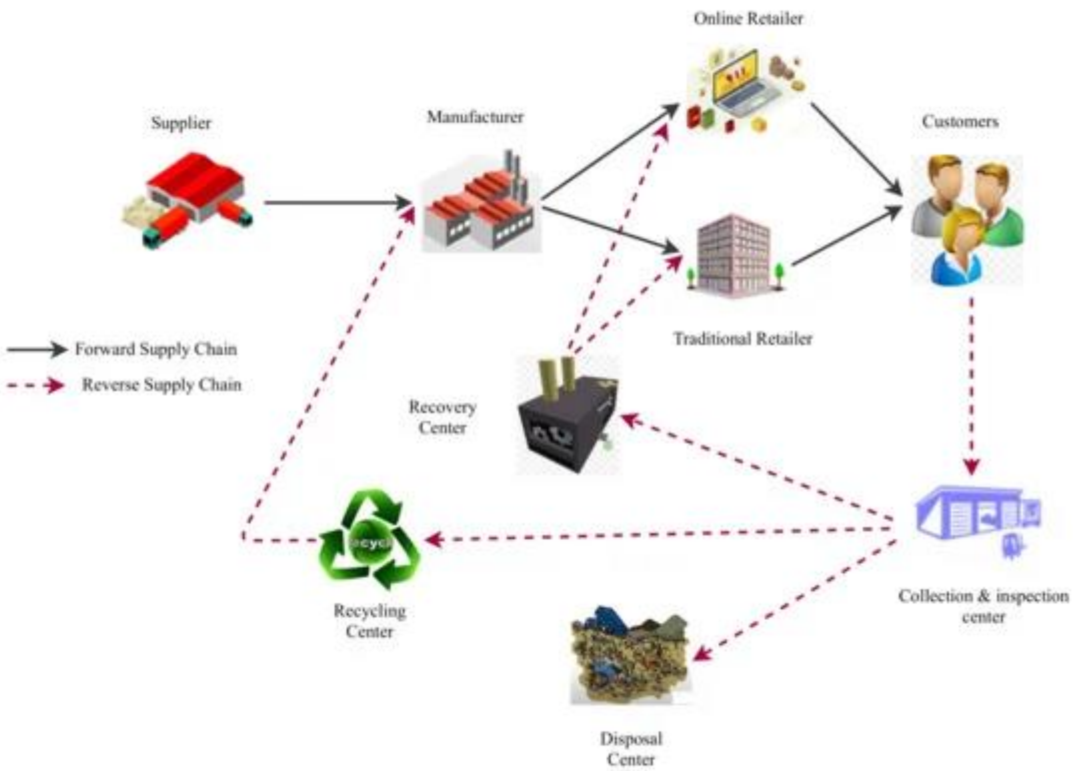

Figure 1 Closed-Loop Supply Chain Network Structure

In terms of RL network typing, as a general guidebook, we can use Moritz's [42] interpretation. Specifically, he divided a reverse network into five basic categories:

i. Mandatory product return networks: The first category is related to the management of used products, which are subject to different regulatory orders. In this case, the various producers and suppliers are legally responsible for removing their products from the various waste streams. However, due to the complexity of the specific project, the recycling process is usually outsourced to a third party that specializes in the field.
ii. OEM product recovery for value maximization: This case is the most common type of network. Specifically, through resource reuse, an organization can add value to a product and therefore achieve its goal of profit maximization.
iii. Remanufacturing networks: Of all the types of RL networks, the reconstruction channels are the ones that made their appearance first. Industrial and automotive equipment is a shining example of material flow in this system. In contrast to the

previous category, a remanufacturing network displays a more complete exchange and brokerage function. Also in this sector, the main driver of activity is the opportunity cost.

iv. Material recovery networks: These systems are based on the recovery of material, either from the same or from different supply chains. Therefore, the nature of the activities of this network type results in exceedingly small profit margins. As is easily perceived since the industry is characterized by its total dependence on the material flow inside the system.

v. Return with refill purpose: In conclusion, the last network is used for container reuse. Soda bottles, oil barrels, etc. are some key examples. The main advantage of this type is the limited number of containers needed for the recirculation of the product, thus cutting down to the minimum the amount of inventory holding and remanufacturing costs.

1.1.3 Sustainable Reverse Logistics

Nowadays, sustainability tries to become an integral part of business activities. Especially in supply chain management, achieving a sustainable competitive advantage has replaced all outdated views about superiority in cost and production volumes [48]. To better grasp the importance of sustainability, we first need to define an appropriate scope of application. Based on the definition given by Muller et al. [109], a sustainable supply chain network (SSCN) can be defined as "a system that integrates environmental and social awareness issues into SC activities without compromising economic output".

Many factors in today's world have resulted in the arousal of research interest regarding the topic of sustainability. Globalization, the proliferation of markets, the world's population's rapid growth rate, and many more drove the scientific community to research more sustainable ways to satisfy global demand [12]. The optimal design of an RL system is established around three main pillars. In more detail, both economic, social, and environmental management can bring to light a truly sustainable system. In addition, the market's complexity and dynamic changes deem the creation of a sustainable strategy an absolute necessity for the maximization of an RL network's performance. However, at the current moment, a different problem seems to occur regarding the simultaneous implementation of both sustainable and resilient practices in the supply chain sector. Nevertheless, in this exact field, there has not been any considerable progress [48, 124].

Over the years, more businesses have optimized their various processes to produce the minimum environmental footprint. This apparent trend towards the adoption of eco-friendly policies has led to the creation of a multitude of models, designs, and applications. The minimization of CO_2 emissions and other waste streams, in combination with the drastic reduction of the use of electric energy and water consumption, are the main indicators for sustainable policies [38]. On the contrary, regarding social corporate responsibility, various employers make significant efforts to increase job positions, provide services to workers, and establish facilities in underdeveloped areas. Those and many more actions shape some important measures that bring us a step closer to sustainability achievement [105].

1.2 Reverse Logistics Optimization

1.2.1 Reverse Logistics Network Design Optimization

The consolidation of RL networks and the achievement of sustainability are two elements inextricably linked. Therefore, the reverse flow of material and information from the customer to the supplier in an RL network can be a factor through which sustainable development can be achieved. Specifically, the operation of a reverse supply chain differs significantly from a forward one. The opposite flow of elements in each category, in combination with the uncertainty of demand and supply, constitutes the main differences between forward and reverse supply chains. Overall, the complexity and unpredictable variation of key variables and factors make designing an inverse network a more challenging and time-consuming procedure than a conventional one [30].

As we can easily understand, the construction of an RL network presents a high level of complexity. By way of explanation, the design of an RL channel is subject to limitations that are directly related to business activity. Specifically, the formation of a plan is established within the framework of three main pillars, which include the various strategic, tactical, and operational decisions that are taken within the boundaries of an organization. Regarding these three hierarchical stages, they are called upon to solve problems related to the optimal establishment of facilities, the perfection of the manufacturing and collection procedures, and the adequacy of suitable vehicles and equipment, respectively, as well as many other issues that burden the work of the administration. [66, 138, 14].

To dive deeper into the reverse network configuration process, we end up enumerating some key processes that frame the specific procedure. In terms of the basic components of a RL network Yang et al. [135] stated that a reverse network consists of the processes of refurbishment and remanufacturing, recycling and repair, reselling, and disposal. Respectively, Ding et al. [33] set as the basic elements of a reverse flow network the procedures of deconstruction, product reuse, waste distribution, and material reprocessing. In combination with the above-mentioned, Van Engeland et al. [125] extended the design model of reverse networks, including heat treatment processes, with the aim of resource recovery and the return of remanufactured products to new markets. In addition, they extended their research to the study of the different forms of a product during the manufacturing process, with these being the levels of material, distinct components, and final product.

Now that we have defined the design framework for RL, the next step is to list the main practical problems that are observed in an RL network. The configuration process of an RL network includes five basic problem categories [96], as reflected in Table 1. Particularly, a reverse flow network faces serious challenges regarding: • The selection of the optimal facility location. • The sequence planning and line balancing in the disassembly line. • The vehicle routing problem. • The general scheduling. Due to the unique nature of each problem, the optimization process of the inverse network changes drastically. As a result, the model used in each case is completely different. If we study the literature holistically, we can limit the main factors that affect the modeling of the network, to five categories. Specifically, according to Abdolazimi et al. [4] the key variables of an RL network configuration are the uncertainty of the provided data, the direction of the material flow, the product quantity of the remanufactured product, the facility's layers, and the research time frame.

Table 1 Basic Problems in RL **[**96**]**

Source	**Problem**	**Definition**
[138]	FL	The determination of a facility's location plays a crucial role in the whole network's optimization. The optimal choice for the construction place of collection, remanufacturing, disposal, and distributing centers influences significantly the total logistic cost.
[23]	DSP	A new problem in the RL. Process sequencing is related to increasing the efficiency of the manufacturing production line, to minimize cost.
[71]	DLB	Similarly, to DSP, DLB is a process of production line planning, with the only difference being that it unifies the various similar processes into distinct workshops.
[53]	VRP	This step comes right after the facility's construction. It refers to the arrangement of vehicle's usage, capacity, and transfer routes.
[86]	Scheduling	Scheduling solely belongs to the remanufacturing procedure. What it does, is determine when, how, and in which quantities of the EOL products will be processed.

In terms of the acquired data, a proposed method can be characterized in general terms by the presence of uncertainty. This uncertainty relates to three basic aspects, which are: the quality of returned products, the returned quantities, and the time frame. Fasihi et al. [40, 17]

categorized reverse networks under uncertainty into four types. In addition, they mapped the basic solutions for each unique model. As stated by the authors [40] the basic standards for network uncertainty are: comprehensive certainty, randomness, epistemic uncertainty, and deep uncertainty. On the other hand, in terms of material flow, we observe three different directions: forward, reverse, and circular, whose analysis has been previously carried out in Chapter 1.1.2. Finally, concerning the three remaining variables, their partial subdivision is related to the existence of multiple or unique elements. For example, the breakdown of processed products refers to whether the reverse production line processes multiple or a single product.

The next step, after the conceptual construction of the RL network configuration and the mapping of the main problems in the sector, is to define the basic solution methodologies. In simpler terms, we need to present the most common models and solution algorithms that are used for the optimization of the different problems we mentioned in Table 1. In the entirety of the international bibliography, one of the most comprehensive studies regarding this topic is the work of Guzman et al. [52]. Specifically, the researchers followed a procedure of recording the most important modeling categories, as well as their proposed solutions, in the period of the last two decades. In addition, it should be noted that this specific study indicated its findings after an extensive investigation of all aspects of reverse logistics as far as planning and sequencing problems are concerned. The results of their research are detailed in Table 2 which contains an analytical overview of RL optimization modeling approaches combined with a set of solution standards.

Table 2 RL Optimization Models and Solution Algorithms [52]

Categories	Analytical Categories			
Modeling Approaches	Binary Programming (BP)		Multi-Objective Linear Programming (MOLP)	
	Constraint Programming (CP)		Multi-Objective Mixed-Integer Linear Programming (MOMILP)	
	Dynamic Programming (DP)		Multi-Objective Mixed-Integer Non-Linear Programming (MOMINLP)	
	Fuzzy Programming (FP)		Multi-Objective Non-Linear Programming (MONLP)	
	Fuzzy Goal Programming (FGP)		Non-Linear Programming (NLP)	
	Fuzzy Linear Programming (FLP)		Quad-Objective Mixed Integer Linear Programming (QOMILP)	
	Fuzzy Multi-Objective Linear Programming (FMOLP)		Mixed Integer Linear Programming (MILP)	
	Goal Programming (GP)		Mixed Integer Non-Linear Programming (MINLP)	
	Integer Programming (IP)		Quadratic Programming (QP)	
	Integer Linear Programming (ILP)		Robust Programming (RP)	
	Integer-Weighted Goal Programming (IWGP)		Stochastic Programming (SP)	
	Linear Programming (LP)			
Solution Approach	**Optimizer Algorithm (OA)**	OA/ Branch and Bound (BB)		OA/ Lomnicki (LO)
		OA/ Branch and Cut (BC)		OA/ Lompen Algorithm (LM)
		OA/ Criss-Cross (CC)		OA/ Simplex (SI)
		OA/ Decomposition Strategy (DS)		OA/ Solution procedure of model P* (SPP*)
	Heuristic Algorithm (HA)	HA/ Benders Decomposition (BD)		HA/ LP and Fix (LF)

	HA/ Beam Search (BM)	HA/ LP Relaxation (LPR)
	HA/ Campbell-Dudeck Algorithm (CD)	HA/ Minimum Spanning Tree (MS)
	HA/ Decomposition & Aggregation (DA)	HA/ Multi-Objective Master Planning Algorithm (MOMPA)
	HA/ Fix-Price-Optimize (FPO)	HA/ Nawaz, Enscore and Ham (NEH)
	HA/ Greedy (GR)	HA/ Nearest Neighbor (NN)
	HA/ Iterative Variable Neighbor (IVN)	HA/ Primal-Dual Based Heuristic (PDBH)
	HA/ Langragian Relaxation (LGR)	HA/ Relax and Fix (RF)
	HA/ Local Improvement Procedure (LIP)	HA/ Relax-Price-Fix (RPF)
Metaheuristic Algorithm (MA)	MA/ Ant Colony Optimization (ACO)	MA/ Scatter Search (SS)
	MA/ Evolutionary Computation (EC)	MA/ Simulated Annealing (SA)
	MA/ Genetic Algorithm (GA)	MA/ Subpopulation Genetic Algorithm (SPGA)
	MA/ GRASP (GR)	MA/ Tabu Search (TS)
	MA/ Iterated Local Search (ILS)	MA/ Tabu Search Grabowski and Wodecki (TSGW)
	MA/ Integrated Greedy (IG)	MA/ Variable Tabu Search (VTS)
	MA/ Memetic Algorithm (MA)	MA/ Variable Neighborhood Search (VNS)
	MA/ Multi-objective Simulated Annealing (MOHSA) algorithm	MA/ Variable Neighborhood Descent (VND)
	MA/ Non-dominated Sorting Genetic Algorithm II (NSGA-II)	MA/ Weighted Sum Multi-Objective Genetic Algorithm (WMOGA)

	MA/ Particle Swarm Optimization (PSO)	
Matheuristic Algorithm (MTA)	MTA/ Ant Colony + Mathematical Model (ACO_MM)	MTA/ Iterated Local Search + Mathematical Model (ILS_MM)
	MTA/ Biased Random-Key Genetic Algorithm + Mathematical Model (BRKGA_MM)	MTA Simulated annealing + Mathematical Model (SA_MM)
	MTA/Fixed Variable List Algorithm and Clustering Sequence Algorithm + Mathematical Model (FVLA_CSA_MM)	MTA/ Tabu Search + Mathematical Model (TS_MM)
	MTA Genetic Algorithm + Mathematical Model (GA_MM)	

Finally, the last important piece in the optimization process of an RL network is the determination of the decision variables, through which we determine the best policies and the decisions we should adopt. The KPIs, as they were called by Mallick et al. [79] include some parameters that express the impact of activity in an inverse flow network. Specifically, these parameters can be categorized into five main topics: financial, environmental, social, operational, and management factors. By extension, each of these indicators can be further divided into smaller subnets. Table 3 lists in greater detail, the above distribution.

Table 3 KPIs in RL Optimization [79]

Aspect	Sub-aspect	Key Performance Indicators
Financial Indicators	Cost	Logistic cost, collection cost for returns, RL cost, cost reduced in anufacturing, reduction in waste disposal costs
	Profitability	Profitability Index, Payback time, profit by recovery efficiency, channel Profit, Return on Investment, Internal Rate of Return, Discounted Payback
	Revenues	Revenues
Environmental Indicators	Emissions	Total harmful emissions, GHG emission reduction
	Energy	Energy self-sufficiency, Use of renewable energy, Energy efficiency
	Pollution	Pollution, eutrophication, toxicity
	Resource Conservation	Material intensity factor, Recovery Rate, Consumption of virgin raw materials, Products diverted from landfill
	Waste	Disposal Costs, Waste reduction, Waste-water discharge
Social Indicators	Customer	Customer Loyalty, Customer Satisfaction, Reduction in customer complaints, Effectiveness in delivery time Expert's opinion, Customer retention, Increase in market share, Customer Health, and Safety
	Employee	Employment possibilities, Occupational Health, and Safety, Excessive Working Hours, Child Labor, Minimum acceptable Wage/Social Equity, Health/Life Expectancy, Accidents
	Supply Chain	Profits to contracted companies
	Other stakeholders	Practices such as those related to stakeholders' expectations of companies' decision-making and macro-social performance in socio-economic and socio-environmental issues
Operational Indicators	Collections	Return Rate, Percent Population served by Collection Centre Network, Provider to Population Ratio (PPR), Average accessibility distance for Collection Centre, Maximum accessibility distance to Collection Centre
	Operations	Cost of Operations, Reduction in production time, Reduction in cycle time of each machine, Reduction in storage capacity requirement
	Packaging	Utilizing end-of-life packaging materials
	Recovery	Recovery efficiency ratio, Reuse rate, Aggregated Quality of Recycling, Waste generated during recovery operations
Management Indicators	Transportation	Better transport capacity management
		Management commitment for RL, Resource investment for RL, Communication with stakeholders, Involvement in RL coordination

1.2.2 Optimal Facility Selection

FL selection is one of the five main problems in reverse supply chain process optimization, as stated in Chapter 1.2.1. Optimal facility placement originates from the fields of computational geometry and operations research. By way of explanation, location analysis, as it's called, deals with the choice of the best location for the establishment of a company's facilities, to minimize the total transportation cost. In addition, the analysis of the optimal position is carried out apart from the operational cost, in consideration of a multitude of other factors of the wider business environment, such as the position of various suppliers and consumers, the area of operation, the availability of the labor force, the existence or not of free trade agreements, the differentiation in a state's tax policy, the adoption of environmentally friendly practices, etc.

Dekker et al. [28] were the first ones that investigated the mathematical modeling of position-occupation problems. Specifically, the researchers constructed a holistic and extensive representation of the sector, also including some of the most widely used optimization techniques. An optimal facility placement problem can mainly be divided into two categories: stable and alterable [91]. Particular attention must be paid to the fact that this variability refers to the possible future change in the location of the facilities and not to the change in the determining factors that affect the initial choice. For example, the stochastic nature of a remanufactured product's demand only plays a significant role in the initial choice's decision and not in its change. As a result, this case belongs to the former category [34]. On the other hand, robust modeling considers potential future changes in the network's structure. The latter modeling approach may prove more useful, given the enormous instability of the global political-economic system as well as the various dangers that are looming in the modern world (wars, pandemics, etc.) [36].

As it is easy to understand, the most important variable for the evaluation of a possible installation position is the cost. Despite this, due to the importance given in recent years to the issue of corporate social responsibility, the weight given to the specific factor has been relatively reduced. Martins et al. [80] proceeded with the formulation of an agile optimization model, applying a heuristic approach under QOS restrictions. Gao et al. [43] used a GIS tool in combination with the DEMATEL assessment approach to optimize a shared energy wind turbine and photovoltaic RL network. Xi et al. [133] proposed a conceptual framework using the particle swarm optimization algorithm and residents' recycling willingness as the decision variables. Using an advanced version of the former approach, Xu et al. [134] showed a positive correlation between the functional costs of a facility and its social acceptance. Wang et al. [128] followed a more qualitatively oriented approach by implementing an analytic hierarchy process (AHP) to optimize a tire waste network. Finally, Becerra et al. [18] studied the combined problem of interdependence between location, inventories, and transportation. By extension, they constructed a MO-MILP model to solve the three sustainability elements (3S) using a lexicographic method.

One of the most important features in the modeling process of an RL optimization problem is the facility's ability to fully (or not) satisfy the overall demand. In the space of reverse supply chains, this dilemma is described by the existence of the model of a capacitated or uncapacitated facility. First, the capacitated facility problem describes the practical scenario in which the demand covering the capabilities of each site is limited. In more detail, the CF problem attempts to locate the optimal facility installation point among a set of alternatives, given a set of demand points, by minimizing the total cost [57]. Regarding the variables that determine the optimal decision, the different modeling approaches to the problem make use of transportation and fixed costs, total market demand, and the facility's capacity [82]. On the other hand, the UCF is one of the most widespread and distinct problems in the field of RL optimization. The problem was first studied by Daskin et al. [81], who pointed out its NP-complete nature. Concerning the gap that it tends to cover, the problem describes the state of a system where the demand is infinite and the ability to cover it from the suppliers is unrestricted. More specifically, the model provides the identification of multiple locations, through which market demand is satisfied and the total variable cost is minimized [72, 126]. The advantage of this particular model comes from the fact that it considers the change in network structure in case it is required [82].

1.3 Goal Programming

Goal programming is a venture that was designed by Charnes and Cooper [24], to find linear solutions to non-linear and non-convex problems. GP is an offshoot of multi-objective programming and can be applied to a wide variety of real-world optimization problems [26]. In general, the basic form of goal programming models can be formulated as follows:

$$Min \sum_{j=1}^{l} P_j \sum_{i=1}^{m} (u_{ij} * d_i^{+} + u_{ij} * d_i^{-})$$

$$subject\ to:$$

$$f_i(x) - b_i = d_i^{+}, i = 1,2,\dots,m$$

$$b_i - f_i(x) = d_i^{-}, i = 1,2,\dots,m$$

$$g_i(x) \leq 0, j = 1,2, \ldots, p$$

where P_j (with $P_j > P_{j+1}$, $\forall\, j$) is the priority factor set for the hierarchy of the various goals, u_{ij} the weight assigned to the positive deviation d_i^+ from the goal i and to the negative deviation d_i^- from the goal i, f_i the model's goal function, g_i the constraint function, l the number of priorities, m the number of goal constraints and p the set of system constraints [26, 60,24].

In multi-objective programming, we assume the existence of different satisfaction levels for each distinct goal. Given this fact, the objective in this case is to minimize the total deviation of the system (both positive and negative) from the predetermined levels. However, the process differs significantly in a real-life scenario. Specifically, under pragmatic conditions, the achievement of one goal is achieved through the sacrifice of another. Consequently, it is correct to define a hierarchy or order of priority, through which the order of fulfillment of each goal is determined [26]. The GP models fall into two main categories: the WGP and the LGP models, which correspond to the former and latter of the above cases, respectively [120]. Over the years, various extensions of GP have come to the surface, trying to optimize the process of meeting goals and expanding the field of application of the method. Some examples are Chebyshev GP [41], Extended GP [101], Meta GP [99], Multi-Choice GP [22], Fuzzy GP, Non-Standard GP, Binary GP, Fractional GP etc.

1.4 Research Contribution

The main purpose of this study is to introduce the reader to the field of RL process optimization and, more specifically, to investigate the problem of optimal location-allocation. This fact is achieved through the presentation of basic introductory concepts and definitions, the analysis of popular models, and their solution methods. Additionally, it records all the research that has been carried out in the specific scientific field, the current research trends and interests, the research gaps in the international bibliography, and the future expansions and directions that will mark the course of the sector. Continuing, the present thesis contributes to the development of a WGP model that can be applied to any business, regardless of its branch of activity, geographical spread, or turnover. Finally, in a broader sense, the study helps in the general deepening of knowledge in the research field, adopting a contemporary approach characterized by equal gravity on both the economic result and corporate social responsibility.

The above objectives are achieved after a thorough analysis of the bibliography. Specifically, the research gaps that the work tends to close are the following: Initially, in previous years, a small number of studies were conducted concerning the adoption of eco-friendly policies in the field of RL networks. Additionally, and about the previous one, the research interest focused exclusively on the aspect of profitability maximization, ignoring the environmental footprint of business activity. Finally, an equally important feature of the proposed model is the theoretical resolution of a network, which has the possibility of branching into multiple countries and any business sector. This assumption will consider the different additional costs of setting up facilities in different countries. Overall, this addition is very practical and useful in everyday life, due to the lack of research on transnational supply chains and the dependence of today's businesses on international trade.

Finally, the interest it piques among the various stakeholders highlights the contribution of the study. By way of explanation, as we mentioned above for the simple reader, this work is a first contact with the RL optimization field, which avoids any unnecessary and invalid information. On the part of the academic community, the thesis could form the basis for conducting further research in the area. Finally, for the private sector, the proposed model contributes to the minimization of business costs while simultaneously conforming the organization to contemporary standards and policies for environmental protection.

All the above are achieved initially with an investigation of the international bibliography as well as the enumeration of the main gaps observed in it. Then follows a brief description of the issue under study, with the aim of its best understanding. Continuing, the theoretical breakdown of the model is conducted, with a detailed analysis of its structural parts and its mode of operation. Given these, the application of the model is applied in a real case, to analyze the effectiveness of the method. Finally, we list the conclusions of the study, its limitations, and some probable future extensions.

2. Literature Review

2.1 Research Methodology

A decisive step in the present thesis is the selection of an appropriate bibliography analysis framework. To establish the theoretical background of the research, we make use of the Webster and Watson [131] literature review methodology. According to them, their model has a great ability to identify relative literature. This is made possible by an initial search, which produces the main part of the bibliographic material, and then, in cases where it is needed, by conducting more focused backward and forward searches, we fill in the bibliographic material. The next step after the finding and presentation of the bibliographic material is the construction of a summary table that contains all the sources, categorized however in the most basic concepts related to the subject under examination. The authors do not set a specific limit regarding the number of identified topics, although they recommend the researcher follow a logical sequence for the selection of the main topics. Finally, in some cases, the option to expand the concept matrix is given. Specifically, we can further divide each category based on each distinct unit.

Regarding the application of the above-mentioned methodology, it is used in the online databases of SCOPUS and WEB OF SCIENCE. Specifically, scientific articles relevant to the optimization of RL chain optimization processes are searched for the period 2022 and beyond. This period is chosen because it is desirable to investigate the subject in the post-pandemic era. Therefore, by limiting the chronological horizon of the search, we try to see the effects that the COVID-19 pandemic had on the research work as well as to study the most contemporary opinions about the specific issue. Despite this, an additional search is conducted, which includes sources of older dates, to complete and supplement the research material.

As far as the research filters are concerned, we set the writing language to "English," the type of sources to "articles," and the type of availability to "all open access". Concerning Scopus's "all open access" filter we mention that its meaning is to give us full academic access privileges, which allows us to access all available articles except the paid ones. As a result, this specific choice does not detract from the quality of the research. Also, the search queries that are captured in each structure are summarized as: • "TITLE-ABS-KEY (reverse AND logistics) OR TITLE-ABS-KEY (closed AND loop AND supply AND chain) AND TITLE-ABS-KEY (optimization)" in SCOPUS and • "Topic: (reverse logistics) AND Topic: (optimization)" in WOS. As a result, we ended up with a total of 343 articles, of which 245 come from SCOPUS and the remaining 98 from the WOS database, as depicted in Figure 2. Explanatory: This set contains 43 irrelevant articles, 17 literature reviews, 1 conference paper, and 46 duplicate articles. In addition, Figure 3 shows the distinct stages of the article rejection process. Specifically, of the original 343 articles, the last 43 were rejected after a preliminary search on the title alone. A total of 46 duplicates were also identified, and therefore rejected. Regarding the accessibility of each article, there were three that we were unable to access. Then, for the remaining articles, we read only the abstracts to find the main topic of each one. At this stage, 138 sources were rejected. The remaining 113 were read and analyzed extrajudicially. In the end, we were left with a set of 92 articles related to the topic of the study, which form the core of the bibliographic review. Finally, and after additional completion of the bibliographic material during the writing of the work, another 47 articles were added, 31 of them applying the backward research method and the rest using the forward approach. This procedure is also reflected in Figures 5 and 6.

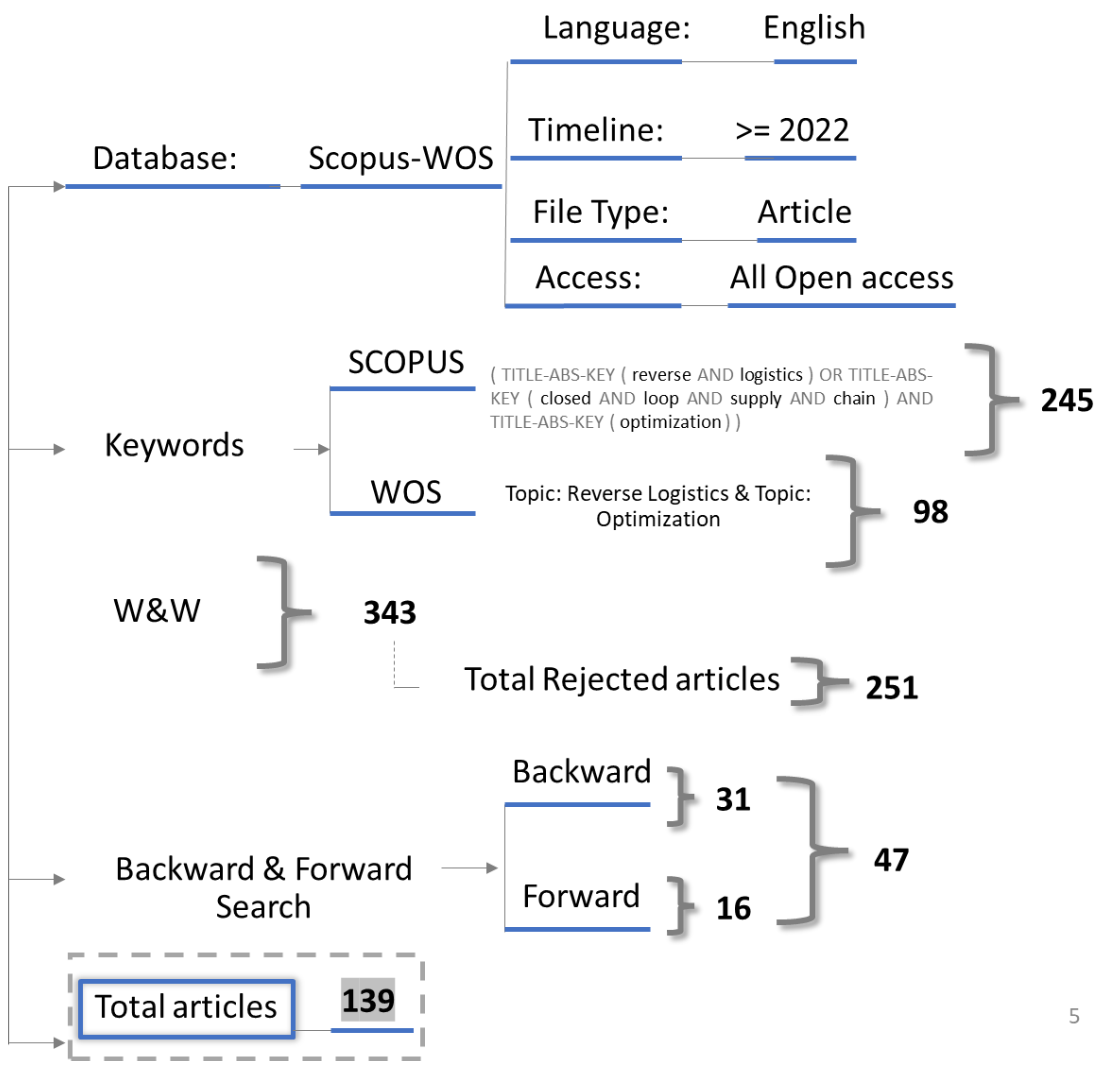

Figure 2 Literature Review Methodology

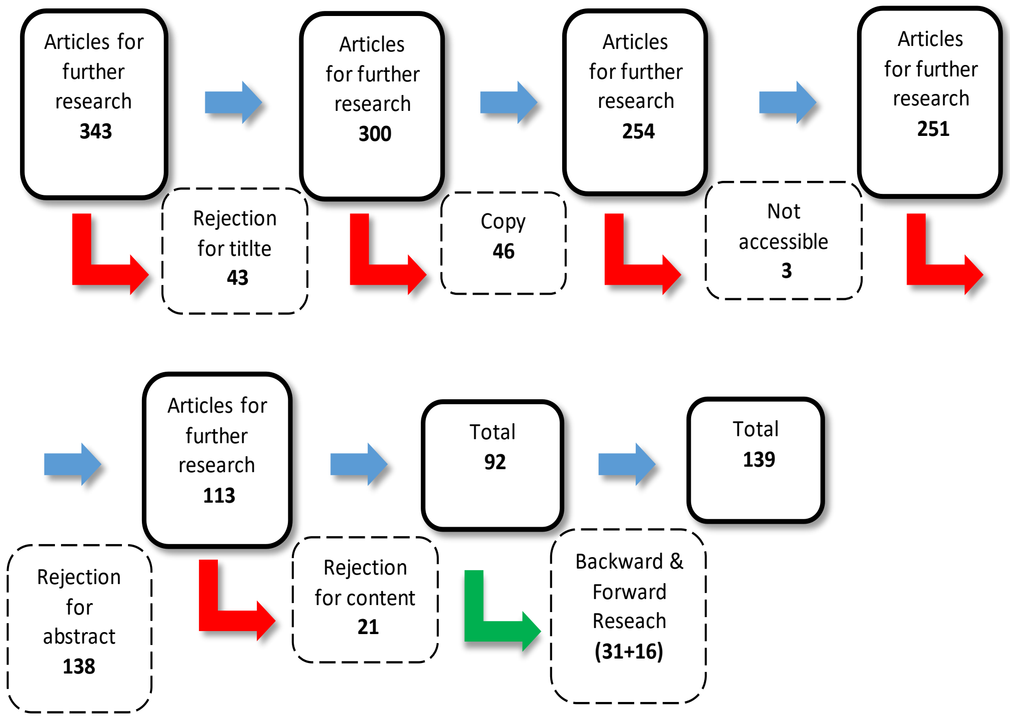

Figure 3 Article Elimination Process

The analysis of Tables 5 and 6 which are the outputs of the Webster & Watson methodology, is also extremely important for another reason. Specifically, Table 5 which is a list of the overall bibliographic material, contains data related to the title of each article, the names of the authors, the year of publication, and the publishing house, as well as the keywords determined by the researchers. It also contains the country in which the research was conducted, the solver, the data collection, and the data analysis methodologies. Regarding Table 6 which is a matrix table, it categorizes the articles based on their subject matter. Specifically, in all the material, we identify seven main categories related to: • Network Design and Optimization [1, 2, 4, 6-12, 14, 15, 17-22, 26, 27, 31-,34, 37, 38, 39, 42-48, 51, 53-55, 57-59, 61-64, 66, 67, 70-72, 74, 76, 77, 79, 81-88, 90-97, 100, 101, 104-108, 110, 111, 115, 116, 119-123, 125-128, 130-132, 134-138], • Optimal Facility Selection [5, 13, 23-25, 48, 60, 68, 73, 75, 78, 89, 98, 102, 103, 109, 113, 117, 118, 124, 129, 133, 139], • Distribution and Allocation [28, 49, 50, 63, 89, 114, 139], • Vehicle Routing [3, 28, 29, 52, 73, 89, 131], • Inventory Management [49, 56, 89], • Recycling and Remanufacturing EOL products [13, 35, 36, 56, 65, 69, 71, 81, 86, 99, 108, 117, 138] and • Sustainability [12, 15, 17, 19, 20, 32, 38, 40, 42, 43, 45, 46, 48, 54, 61, 66, 78, 79, 89, 90, 92, 93, 99, 112, 114, 115, 119, 125, 132, 136].

2.2 Important Findings

According to the Webster & Watson methodology, the results of this search are summarized in Table 6. Ren et al. [96] attempted to categorize all the different combinatorial problems in the EOL remanufacturing sector, identifying the research gaps and proposing some directions for future work. Similarly, Zhang et al. [138] presented the most critical areas of interest in the field of RL remanufacturing. Also, the research of Tao et al. [121], Guzman et al. [52], and Elwany et al. [37] presented a set of RL network optimization models as well as their solution approaches. Van Engeland et al. [125] and Muthusamy et al. [13] proceeded to map the literature in the field of reverse supply chains. The first ones conducted their research from the side of waste management and integration maximization, while the others followed a more comprehensive approach by investigating the entirety of a closed-loop system. The work of Sinha et al. [114] led to the development of an analytical framework in terms of the three R's (recycle, reuse, and remanufacturing) in RL. Lastly, Ding et al. [33] studied the forward and RL processes in building the life cycle.

The bibliographic review in Chapter 2.1 allows us to draw some important conclusions. Specifically, the mapping of the most basic research fields in the RL sector, the enumeration of the main optimization models, and the solution methodologies that have been used in recent years. It also helps us with the finding of the most basic optimization tools and solvers, the presentation of the different optimization criteria, and lastly, the different objects on which the procedure is applied. About the mapping of the main research fields, a conceptual map is created through the Gephi software, which describes the research orientation in the field. Specifically, it is observed that the research material deals with nine basic categories of problems. These categories are related to topics such as: • Network Design (green), • Energy Saving (light pink), • Innovation (red), • Inventory Management (black), • Remanufactured Products (purple), • Strategic Decisions (blue), • Law (grey), • Client Satisfaction (pink), and • Economic Optimization (teal). In Figure 4. we can observe with distinct colors each group, as well as the subcategories into which each is subdivided. In addition, it should be noted that the total sum of observations in all subcategories represents the 251 articles that passed the stage of detailed analysis. As it is easy to understand, most of the research of recent years has focused on the design and optimization part of inverse networks, either by maximizing the performance of existing algorithms and procedures or by studying the system from the side of sustainability.

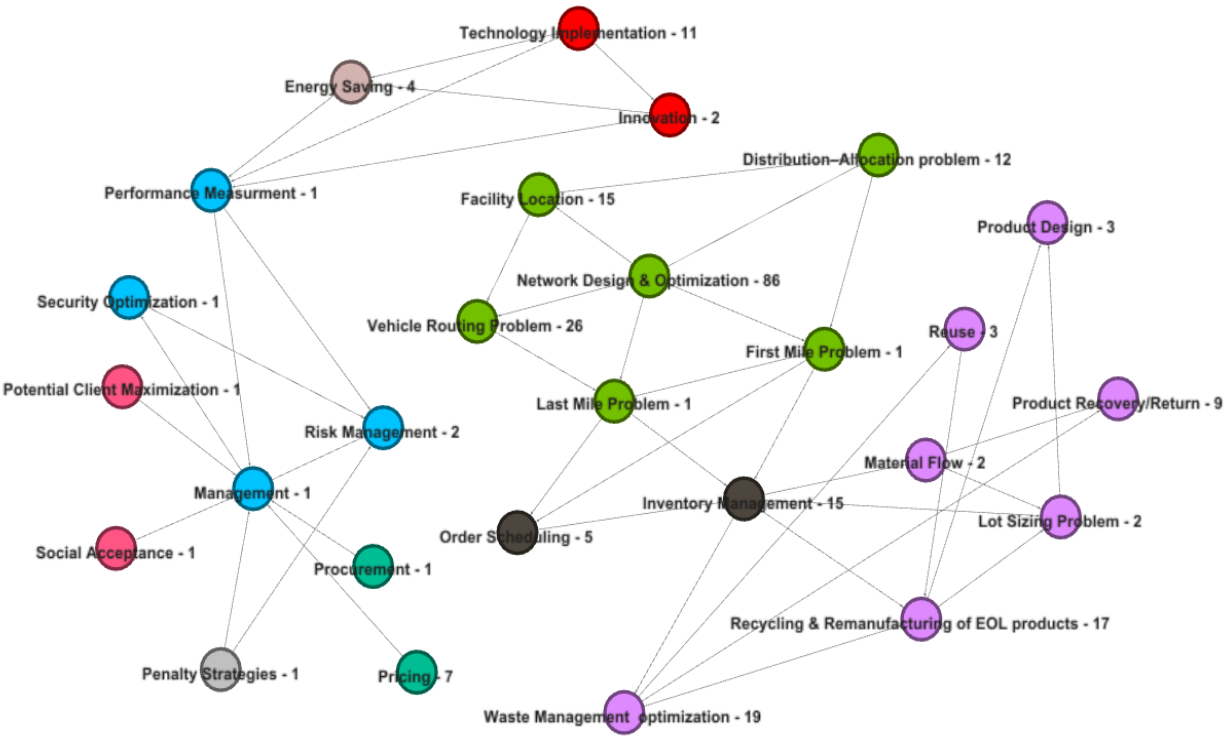

Figure 4 Conceptual RL Map

The rest of the useful extracted information we mentioned above is presented in Figures 5, 6, and 7. Specifically, concerning the optimization models, we observe an obvious dominance of MILP models. Additionally, in cases of parameter uncertainty, it is more common to use the fuzzy and stochastic optimization methods. Regarding the optimization criteria, we notice that the vast majority of research is limited to the factors of cost and the minimization of CO2 emissions. However, we can understand that this fact is natural because these factors represent, to the greatest extent possible, the effectiveness of business activities. Additionally, there is a growing trend to use profitability and social impact as optimization factors. From the side of application fields, we see an increasing interest mainly in supply chains of electrical equipment, such as batteries and EOL vehicles. However, we are seeing increased activity in the medical waste and pharmaceutical equipment sectors, confirming the impact of the pandemic on research work.

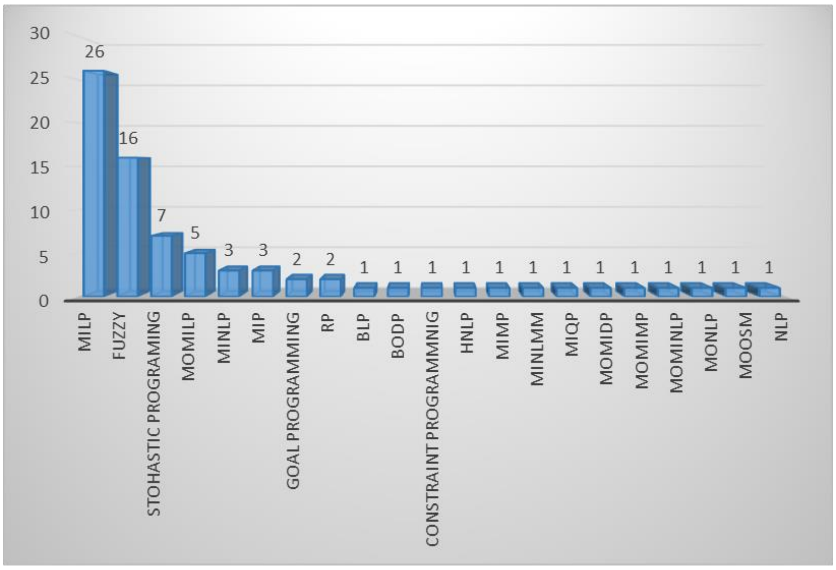

Figure 5 Optimization Models

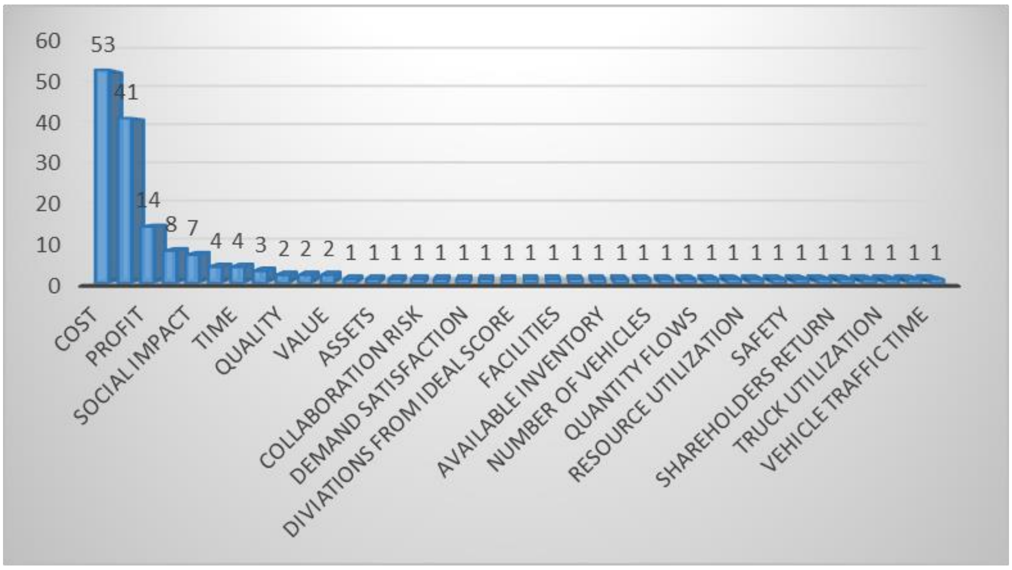

Figure 6 Optimization Criteria

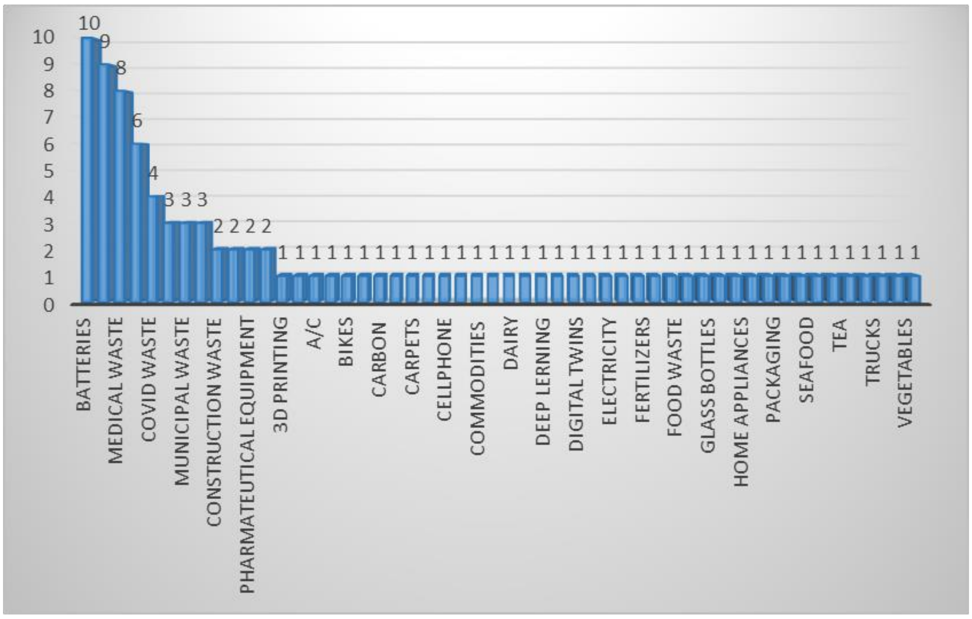

Figure 7 Optimization Applications

Another important fact is the finding of the main solution approaches. More specifically, our research indicated the use of three basic categorical methods. Concerning deterministic models, optimization algorithms such as the Analytic Hierarchy Process and the K shortest path algorithm are used. In cases where the weight of resolution speed outweighs the need for accuracy, researchers prefer the use of heuristics. Some examples are Bender's decomposition, Lagrangian relaxation, etc. On the other hand, in cases of combinatorial problems with many practical solutions, meta-heuristic methods are used. Although the specific methods do not assure us of finding the global optimal solutions, they usually show better results than the previous methods on problems of high complexity. The identified approaches consist of the Relaxation Particle Swarm, Ant Colony, NSGA II methods, etc.

Table 7 Observed Solution Approaches

	SOLUTION APPROACH
Heuristics	BENDERS DECOMPOSITION
	LANGARIAN RELAXATION
	LP METRIC METHOD
Metaheuristics	PARTICLE SWARM
	SIMULATED ANNEALING ALGORITHM
	ADAPTIVE LARGE NEIGHBORHOOD SEARCH
	ANT COLONY
	ARTIFICIAL BEE
	GRAY WOLF OPTIMIZER
	MOGA II
	NSGA II
	NSGA III
	TABU SEARCH
	WHALE OPTIMIZATION ALGORITHM
	CUCKOO OPTIMIZATION ALGORITHM
Optimizer Algorithms	K SHORTEST PATH ALGORITHM
	MILEAGE SAVING PATH 0-1 PLANNING MODEL
	ANALYTIC HIERARCHY PROCESS

Finally, we record all the solvers that are used in all the research that we studied. We observe the existence of a multitude of methods through which the optimization of the models under consideration is carried out. In more detail, the different methodologies are summarized in the categories of simulation software, the use of programming languages, mathematical modeling platforms, and ready-made solvers, as depicted in Figure 8. In the first category, we observe the use of simulation software like ARENA and OPTQUEST. About programming languages, we note the extensive use of the Python and Julia programming languages. Additionally, the modeling platforms that helped carry out the research were GUROBI and MATLAB. Finally, the solvers that were used include IBM ILOG CPLEX, GAMS, LINGO, and RELOG.

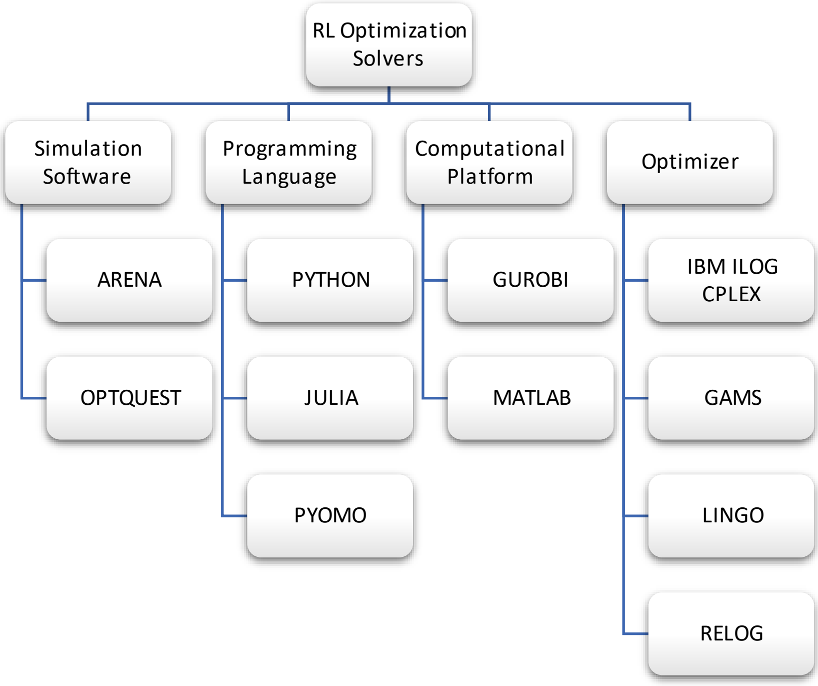

Figure 8 Optimization Solvers

3. Proposed model

3.1 Problem Description

The present thesis differs from the rest of the literature because, in contrast to previous studies tries to solve a capacitated facility location selection problem while integrating the environmental footprint of business activity into the optimization process. More specifically, we develop a model that uses transportation costs as well as total CO_2 emissions as its primary categories of optimization. Concerning the theoretical construction of the model, we try to identify the optimal location for establishing a set of facilities that will serve several waste collection centers. More specifically, we start the planning process by selecting some locations for the installation of processing centers, taking for granted the already existing waste collection points of the enterprise. With the subsequent application of the proposed methodology, these centers are examined, and finally, the most suitable ones are selected. The set of elements is represented in a pragmatic coordinate system, with the aim of easy understanding and resolution of the model. Given the coordinates of each point, we calculate the distance of each processing center from each collection point. Then, knowing these distances, we can calculate the total transportation cost for each remanufacturing center from a specific collection point. This amount is the product of the kilometer distance, the total transported quantity from the collection center to the processing facility, and the average cost for each unit per kilometer. In addition, we can calculate the CO_2 pollutants per route as the product of the transported quantity, the kilometer distance, and the average amount of CO_2

emissions for each unit per kilometer. Given all that was mentioned above, we approach the solution of the model using a WGP approach. The problem's analysis is represented below, in Figure 9.

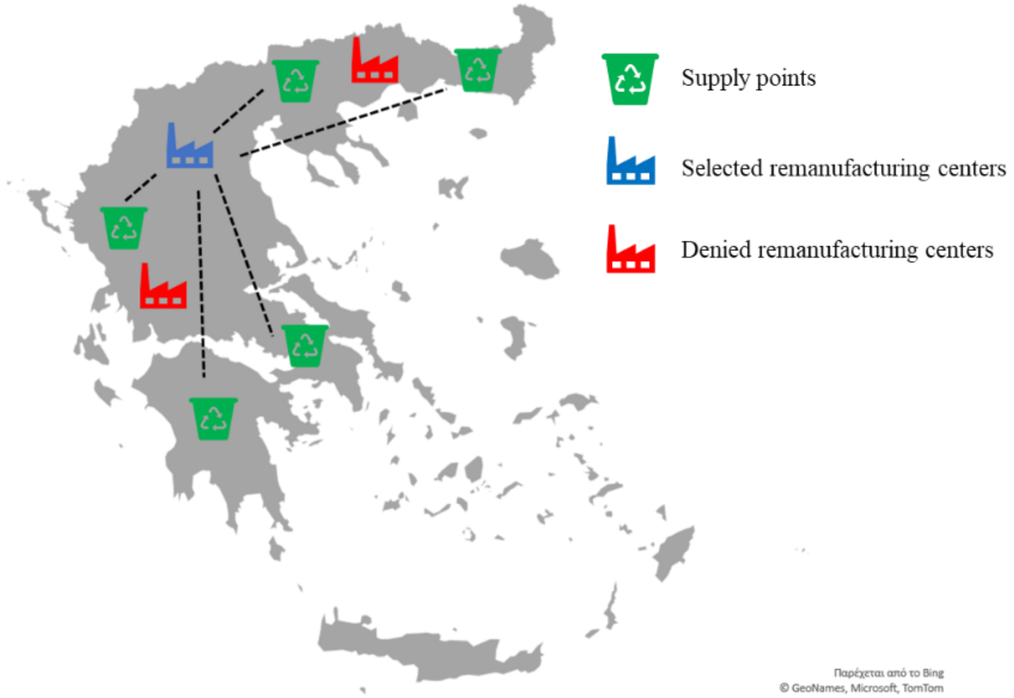

Figure 9 Problem Representation

3.2 Basic Assumptions

The construction of the proposed model presupposes the making of certain assumptions regarding the system's operation. First, the model under examination is a CF location selection model. Therefore, the capacity of the possible factories as well as the market offer are regarded as given and finite quantities. We additionally assume that the size of the remanufactured quantity is expressed on an annual basis. Consequently, the timeline for the decision-making process is equal to one year. Additionally, these quantities can be calculated using predictive mechanisms using past data. Another important assumption refers to the way of calculating the distance between the system's elements. Specifically, the distances from each collection point to the processing center are calculated using a pragmatic approach using Google Maps software. However, a main limitation of the methodology is that, in real life, the shortest route is not only chosen based on distance but also given various other factors such as traffic on a road, emergency events, etc. Finally, it should be mentioned that the cost part of the objective function that we analyze below includes only transportation and construction costs. The other operational costs that bore the business are not considered because it is assumed that they are independent of the geographical location of the installation.

3.3 WGP Model Structural Parts

In terms of the CF location problem's solution, we try to find the optimal locations for the installation of remanufacturing centers from a set of feasible options that satisfy a set of collection points. Regarding the structure of the model, a WGP approach is carried out, which aims at minimizing the deviation of the factory's performance from predetermined goals. More detailed, these targets refer to the sum of the transportation and construction costs of each factory and the total CO_2 emissions resulting from each option. The two goals are also subjected to weighting, which indicates the gravity and importance of each one of them. Finally, it should be mentioned that the construction of the model is being carried out keeping in mind its dynamic application, regardless of the field of activity of the business under examination as well as the spatial context of the corresponding RL chain. Despite this, like all other models, this framework is also able to show certain weaknesses as well as accept certain extensions and modifications. In this stage, we do not expand further on this matter; however, we will analyze this specific subject in more detail in Chapter 5.

The subsequent chapters describe the structural parts of the proposed WGP model. Therefore, according to the specific methodology, the model consists of three basic structural parts: the determination of the parameters and the decision variables; the clarification of the performance objectives and the deviation variables; and finally, the construction of the model. The last part includes the determination of the economic and goal constraints, as well as the construction of the objective function.

3.3.1 Parameters and Variables

Table 8 WGP Model Parameters and Variables

Sets:
F: facility locations , i = 1, ... , n for $i \in$ F
S: supply points , j = 1, ... , m for $j \in$ S

Parameters:
C_i: capacity of facility i
S_j: supply from supply point j
$\{x_i, y_i\}$: $\{x, y\}$ coordinates of facility i
$\{v_j, z_j\}$: $\{x, y\}$ coordinates of supply point j
d_{ij}: distance from facility i to supply point j
MTC: mean transportation cost per 1 km of transportation for 1 unit
ME: mean CO_2 emissions per 1 km of transportation for 1 unit
TTC_i: total transportation cost of facility i
CC_i: construction cost for facility i in coordinates $\{x_i, y_i\}$
TC_i: total cost of facility i
TEi: total emissions of facility i

Decision Variables:
f_i=1 or 0 (for facility i being open or closed)
U_{ij}: (for total supply being assigned to facility i from point j)

Table 8 contains the parameters and the decision variables of the proposed model. Bear in mind that the theoretical model consists of two basic categories of elements: the set of various locations for the installation of processing centers (F) and the number of already existing waste collection points (S). With reference to the description of the model's parameters, we observe the size of the annual capacity of each factory (C_i) in combination with the total annual supply of each collection point (s_j). We also gather the coordinates of all the elements of the model and calculate the distance between them (d_{ij}). We also need the parameter MTC that describes the average cost of transporting a unit of returned product for each distance unit and the parameter ME that expresses the CO_2 emissions of each unit per distance unit. In addition, the parameters TTC_i, CC_i, TC_i express the transportation cost, the construction cost, and the total cost of each factory, respectively. The parameter TEi expresses the total CO_2 emissions for each factory, respectively. In each case, the detailed analysis of each variable is carried out below. Finally, the decision variables consist of the variable (f_i) that indicates the installation or not of a factory and the variable U_{ij} that expresses the size of the total returned quantity, allocated from the point j to the facility i.

$$TTC_i = \sum_{\mathrm{i=1}}^{\mathrm{m}} d_{ij} \times \mathrm{MTC} \times U_{ij} \ (1)$$

$$TC_i = CC_i \times f_i + TTC_i \ (2)$$

$$TEi = \sum_{j=1}^{m} d_{ij} \times ME \times U_{ij} \times f_i \ (3)$$

The above equations describe the formulas for calculating the total transportation cost, the total cost, and the total emissions for each factory, respectively. Specifically, equation 1 calculates the total transportation cost of a factory i as the sum (for each collection point) of products of the distance traveled from a collection point j to the remanufacturing center i (d_{ij}), the average transportation cost (MTC), and the total transported quantity from j to i (U_{ij}). Equation 2 calculates the total annual cost of each potential facility as the sum of the construction cost of each facility i over the binary variable fi, which expresses whether the factory has opened or not, and the total transportation cost CC_i of the facility. Finally, equation 3 calculates the total amount of CO_2 emitted by a factory as the product of the total distance traveled from the collection point j to the factory i (d_{ij}), the average emissions (ME) for each unit of returned product per unit of distance, the total transported quantity (U_{ij}) and the binary variable f_i.

3.3.2 Objective Function

In this chapter, we analyze the structural parts of the objective function of the WGP model. Initially, in the case of a conventional linear programming problem, we would try to minimize the magnitude of the total cost and CO_2 emissions, as seen in expressions 4 and 5. Nevertheless, the proposed model tries to achieve the simultaneous minimization of deviation from the predetermined performance targets of the above two quantities using a weighting mechanism that indicates the priority given to each factor. As depicted in Table 9, the weight of each objective is represented by the variables W_1 and W_2, which make up the weight coefficients of the cost and the produced pollutants, respectively. In addition, the variables dTC^-, dTC^+, dTE^-, dTE^+ indicate the positive and negative deviation from each partial goal. In other words, they tell us whether each goal was achieved or not.

$$Min \sum_{i=1}^{n} TC_i \ (4)$$

$$Min \sum_{i=1}^{n} TE_i \ (5)$$

Table 9 WGP Model Weights and Deviation Variables

Weights
W_1: weight for the total cost objective
W_2: weight for the CO_2 emissions objective
Deviation Variables
dTC^-: underachievement of total cost
dTC^+: overachievement of total cost
dTE^-: underachievement of total CO_2 emissions
dTE^+: overachievement of total CO_2 emissions

The minimization model includes as structural elements the total cost and total emissions, which are equal to the variables Z_1 and Z_2 respectively, as depicted in equations 6 and 7. We also need two more variables gTC and gTE, which are the quantitative targets or performance indicators for Z_1 and Z_2. Relation 8 describes the cost target as the sum of the variable Z_1, with the negative and positive deviations of the actual size from it. In addition, according to equation 9, the pollutant goal is presented as the sum of the variable Z_2 with the positive and negative deviations of the actual amount from the target.

$$Z_1 = \sum_{i=1}^{n} TC_i \ (6)$$

$$Z_2 = \sum_{i=1}^{n} TE_i \ (7)$$

$$Z_1 + dTC^- - dTC^+ = gTC \ (8)$$

$$Z_2 + dTE^- - dTE^+ = gTE \ (9)$$

The last part that remains is the construction of the objective function. It would be reasonable to assume its form as the sum of the variables Z_1 and Z_2 multiplied by the weighting coefficients W_1 and W_2. However, because the two variables express two different quantities, the result we would get would have no basis. For this reason, we decided to perform a normalization of the data. In other words, we decided to replace the variables of the absolute quantities Z_1 and Z_2 with the percentages of achievement for each goal. This specific action would free us from the calculation of dissimilar quantities and would help to extract reliable results. Specifically, expression 10 constitutes the modified objective function. It should be noted that the objective function can also take negative values. This is done because the goal is not only to minimize the weighted negative deviation from the target, but also to maximize positive performance. Therefore, the final form of the objective function consists of the sum of each goal's achievement percentage, divided by the weighting index of each goal.

$$Min\ W_1 \times \left(\frac{dTC^- - dTC^+}{gTC}\right) + W_2 \times \left(\frac{dTE^- - dTE^+}{gTE}\right) \quad (10)$$

3.3.3 Constraints

The above model cannot be established without the existence of certain constraints that regulate the sizes of the parameters and variables so as not to exceed normal levels. Starting with the constraint categories, we have the goal constraints. This specific class is illustrated by equations 11 and 12 and implies that the actual magnitudes of the variables Z_1 and Z_2 affected by the deviation variables, cannot differ from the predetermined targets. The second category of restrictions is the economic ones. Specifically, relationships 13 and 14 represent this category. In more detail, relation 13 indicates that the total transferred quantity to all centers from a specific point j must equal the total returned quantity of the point j. On the other hand, relation 14 describes that, the total quantity returned to an installation from all collection points, should not exceed the plant's i capacity. The last category of restrictions is related to the allowed values that the variables of the model can take. For example, the binary variable fi equals the decision to open a facility if it takes the value 1. On the contrary, if it takes the value 0, the factory will not be built. Also, relation 16 keeps the sum of the two weight coefficients equal to 1. Finally, relations 17 and 18 imply the non-negativity of the transportation cost, manufacturing cost, total emissions, returned quantity, and deviation variables.

$$Z_1 + dTC^- - dTC^+ = gTC \quad (11)$$

$$Z_2 + dTE^- - dTE^+ = gTE \quad (12)$$

$$\sum_{i=1}^{n} U_{ij} = S_j, \forall j \in S \quad (13)$$

$$\sum_{j=1}^{m} U_{ij} \leq C_i * f_i, \forall i \in F \quad (14)$$

$$f_i \in \{0, 1\}, \forall i \in F \quad (15)$$

$$W_1 + W_2 = 1 \quad (16)$$

$$U_{ij}, dTC^-, dTC^+, dTE^-, dTE^+ \geq 0, \forall i \in F \,\&\, \forall j \in S \quad (17)$$

$$TTC_i, CC_{i,} TC_i, TE_i \geq 0, \forall i \in F \,\&\, \forall j \in S \quad (18)$$

4. Case Study

This chapter includes the application of the above model to a real corporation. In this effort, finding reliable data, through which we will feed the model, is vital. For this reason, communication was attempted with several companies, to supply us with the required data. Despite this, after an extensive search, no company was found willing to take part in the research. Therefore, with the aim of not reducing the reliability of the results of the study, we used combined data that we obtained from online libraries and sources. In this point, we should mention that our imaginary case study refers to a reverse supply chain of ink and toner cartridges. In addition, we studied the specific reverse channel in the geographical region of Thessaly, in Greece. The purpose of the procedure is the selection of the best topographic point for the installation of a remanufacturing center, given the different waste collection points, which are scattered in the specific area. As mentioned in the previous chapter, to achieve the above purpose the WGP method is used. Finally, the program which is used for the construction but also the solution of the problem, is the Excel Solver, due to its straightforward application.

4.1 Data Acquisition

The first and most basic step in the implementation of the study is the geographical identification of the waste collection points and the possible installation points. For this part, we looked at the Appliances Recycling S.A website where we found a map depicting the company's toner and ink cartridges network. The network is represented in Figure 10 which determines the set of points using the Google Maps application. To complete the network, we placed on the map the possible points for the construction of the remanufacturing centers. Overall, the former are depicted as the green icons, while the latter are represented by the red ones.

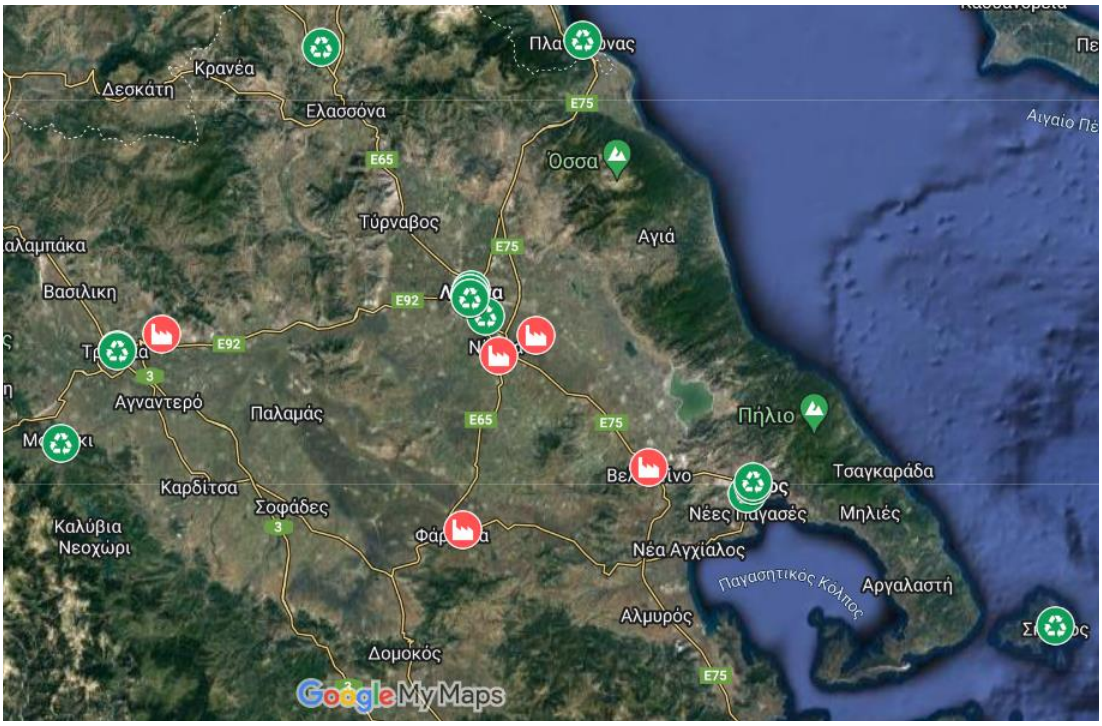

Figure 10 Map Depiction of Case Study Network

Having a complete picture of the network's structure, we can very easily calculate the distance of each collection point from each installation. In total, the geographical coordinates of each element, as well as the total distances, are shown in Tables 10, 11, and 12. One thing worth noting is that the distance matrix includes the distance between two elements, which is measured in kilometers. Also, we mention that for the calculation of the specific distance, the Google Maps app was used and includes the actual distances that a vehicle needs to travel, to get from one point to another.

Another key element is the calculation of variables of average costs and CO2 emissions. Starting with the easiest, the average CO_2 emissions were calculated with data we extracted from the internet. Specifically, according to a 2021 study conducted by the European Federation for Transport and Environment [112], the average emissions of a 5-LH type vehicle that has a market share equal to 61.8% (Figure 11), amounts to 56.6 g/tone kilometer (Figure 12). On the other hand, determining a representative size for the average cost constant is more complicated. For its calculation, information was drawn from the European Commission's 2023 report, which states that the average diesel consumption in the 5-LH type category amounts to 24 liters per 100 g/tone kilometer. Based on this, we calculated the average consumption per g/tone kilometer and then multiplied it by the average diesel price in Greece for the year 2023. The above calculation gave us the average cost of 0.39216 euros per g/tone kilometer. At this point, it should be noted that, although these quantities are based on real data, the lack of perfectly representative data limits the research to a specific type of vehicle application. In addition, there is the weakness that the company may not use these vehicles we are considering. All these facts, although they do not deprive the model of its credibility, significantly reduce the realism of the produced results.

The inability to find data led us to randomly determine the size of the annual returnable quantity of each collection point, the maximum possible processed quantity from one plant, and its total installation cost. Specifically, we made use of the Excel RANDBETWEEN() function, by delimiting extreme values that correspond to data we found on the Internet. In no case this data can be characterized as dependable, however, they help us with the simple application of the model. By extension, the limits of each set are 1-100 tons of returned products, 100-1000 tons of remanufacturing capabilities, and 1-4 million euros, respectively. The last part is the determination of the individual cost and emission targets in combination with the determination of the achievement weights of each target. Unfortunately, because there was no collaboration with any companies, we instinctively set these sizes. Specifically, the annual cost and pollution targets were set at 5 million euros and 60 tons of CO2, respectively. Furthermore, the determination of the weighting factors amounted to 55% for cost and 45% for CO_2 emissions. All the above-mentioned data are depicted in Tables 13, 14, and 15.

4.2 Problem Framing

Figure 13. illustrates the modeling of the problem in the Excel spreadsheets. To begin with, the first table is an assignment table, through which the return quantity transferred from a collection point to a potential factory is determined. For example, the cell (F2,S7) represents the quantity returned from the seventh point to the second factory. Continuing, the "Open facility I" column includes values of a binary variable. These values determine whether an

installation will be constructed or not. Specifically, the value 1 represents the decision to build a factory, while the value 0 represents the rejection of the above decision. The adjacent column named “Supply to location” , indicates the total returned quantity in a facility and is calculated as the sum of the returned quantities of each collection point to a specific factory. The last column named “Capacity” represents the annual processing capabilities for a given factory. Going down to the green frame we observe the constraints of the returned quantity. The first line with the blue arrow represents the actual total amount returned from a specific collection point. Conversely, the line with the red indicator represents the total annual returned quantity of each collection point. Lastly, the minimum cost frame represents the total cost you get, after applying the solution process.

Continuing the second table is the matrix of CO_2 emissions. Each element measures the annual CO_2 emissions caused by the returned products from a specific collection point to a specific factory. It should be noted that the completion of the matrix is conducted automatically and simultaneously with the initiation of the solver and each of its cells is the product of the tones in the returned quantity between two elements, the total distance traveled between the two elements, and the constant of average emissions. Like the total cost, the cell of the total emissions gives us the emissions of the optimal process, which equals the sum of all the cells of the table. Here we should point out that the total generated cost and the total emissions are not the total minimums. Despite this, their combination produces the optimal results based on the WGP model we use. Now that we have identified these two quantities, we can very easily calculate their deviation from the predetermined targets. Deviations of each target are displayed in the corresponding cells. In addition, each variable can take any value, with positive values being equivalent to not achieving the goal and negative values for achieving it. Finishing with this data and using the expression 10 of Chapter 3.3.2 we can find the total deviation from the expected results. Negative values of the objective function indicate a positive deviation from the predetermined goals, equivalent to the optimization of the selection process. On the contrary, positive values are equivalent to a negative deviation from the predetermined goals, with the result that we will not achieve the goals we set.

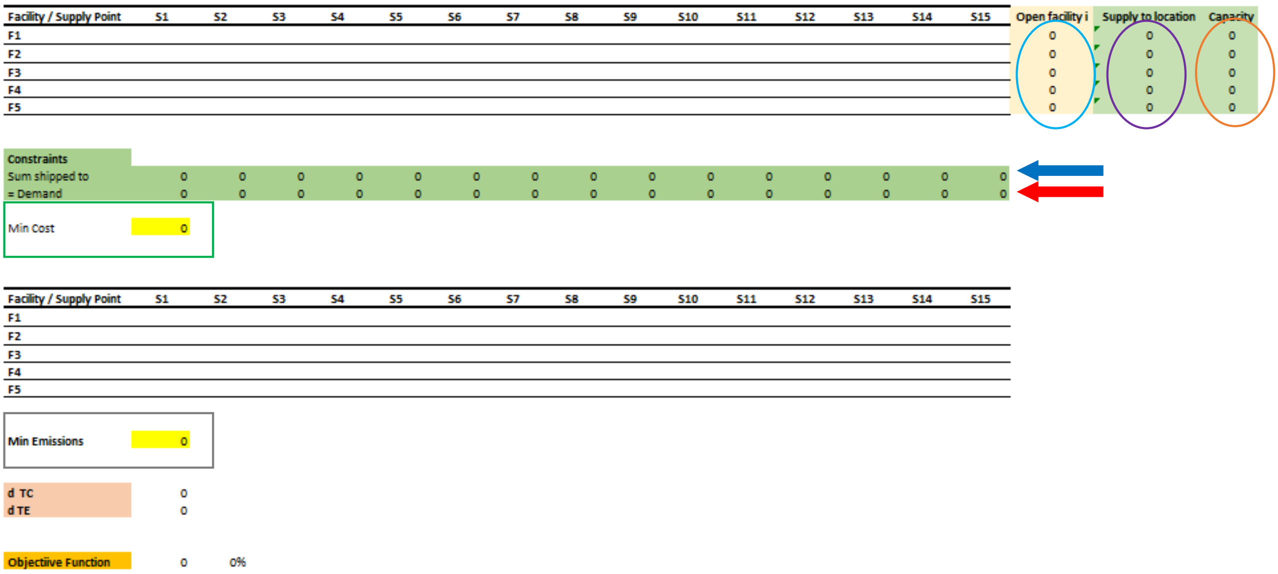

Figure 13 Excel Problem Framing

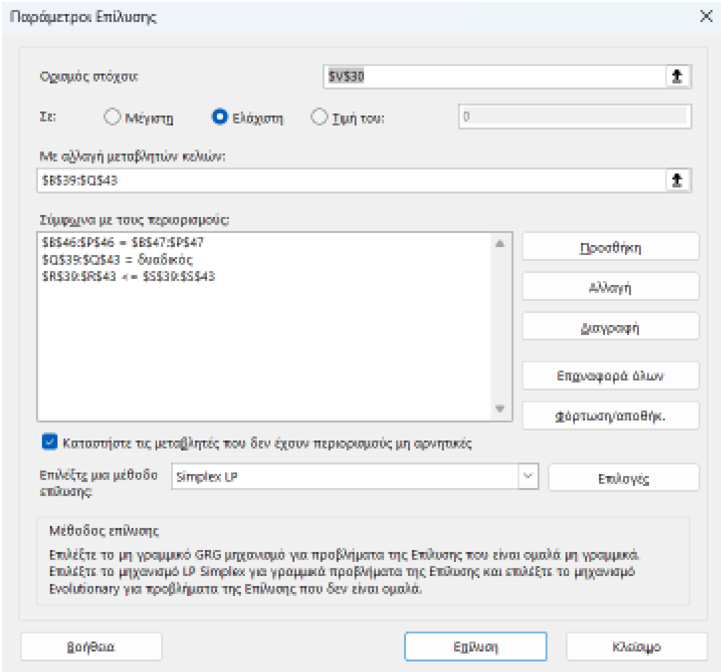

Figure 14 Excel Constraints

Regarding the solver setup, we can observe the set of constraints and decision variables in Figure 14. Initially, the objective cell refers to the optimization of the objective function cell. Additionally, the optimization will be achieved by minimizing the above value, using the Simplex LP method. Subsequently, the frame for changing the cells refers to changing the decision variables, to optimize the model. Specifically, the return quantities variable is contained in the assignment matrix and the facility establishment variable is in the column “Open facility i”. Moving on, we note a set of three constraints. Explanatory the first one refers to the fact that the total annual capacity of each collection point must be equal to the total actual returned quantity from this point. The second describes the binary nature of the establishment column values. The last constraint describes that the annual returned quantity accepted by a facility cannot exceed the total annual capabilities of the specific factory.

4.3 Computational Results

The final step of the process is the initiation of the solver. The application of the solution procedure resulted in the production of the results that appear in Tables 16 and 17. Specifically, the application of the model indicated the combined establishment of plants 3 and 5 as the optimal action. More specifically, in the following table, we can observe the quantity supplied by each collection point to each factory, as well as the total exploitable capability of each factory. For example, point 1 gives 55 tons of returned material to plant 3, point 2 31 tons, etc. Concerning the capabilities of each facility, we see that plant 5 is fully exploited, along with plant 3 which will have an activation rate of 23%. These specific results led to the production of a total cost equal to 5131636.016 euros, a size which is equivalent to a negative deviation from the target by 2.63%. On the contrary, the total produced CO_2 emissions amounted to 57824598.51 grams or more than 57 tons, a fact that results in a positive deviation from the target by 3.63%. Collectively, the objective function given the above inputs gave us a combined positive deviation of 0.18%. This fact indicates the achievement of the company's goals collectively and strengthens the validity of the choice made.

Table 16 Final Assignment Matrix

Facility / Supply Point	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	Open facility i	Supply to location	Capacity
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	55	31	82	0	4	0	0	0	0	54	0	0	0	0	0	1	226	966
F4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	13	90	61	93	59	12	0	44	22	34	90	76	1	594	594

4.4 Sensitivity Analysis

In this chapter, we conduct a sensitivity analysis, in the above case. Specifically, we explore all supply chain returns by setting up different combinations of the weight factors. We should mention that these combinations change by 5 percentage units and have an interval from the first to the third quartile for each distinct coefficient. We could very well widen this interval, for example, to set a combination of 10% and 90%. However, in this case, we would limit the possibilities of the model to investigate the joint effect of the cost and emission factors. Concerning the form of Figure 15 each stacked column consists of two parts. The orange is the emissions factor, while the blue one is the cost's weight factor. We can also observe the trend line which includes the optimal values of the objective function for each different combination. Specifically, we observe that the optimal result is achieved if we set the weight of the cost and emission factors at 25% and 75% respectively and it is equal to a positive deviation of 13.4%. In addition, we see that as we change the ratios in favor of the cost part, the performance of the system decreases. The interest lies in the fact that until the point of the proportion of cost-emissions (65% - 35%) the solver continues to give the same assignment results. Also at this point, the minimum systemic performance appears. Despite this, after this point, the performance shows an upward trend, and the results of the solver condemn factory 2 as the only optimal solution. This behavior is explained by the fact that most of the collection points are located near the factory. Thus, in cases where the cost factor is more important, the objective function depends mostly on the total distance traveled, which means that we choose the facility that is closest to the most collection points.

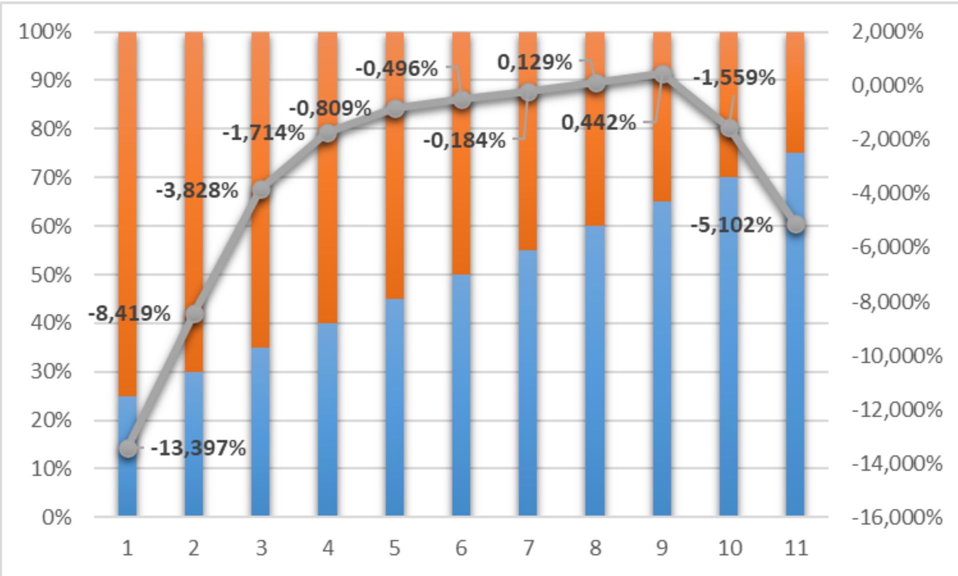

Figure 15. Sensitivity Chart

5. Conclusion and Future Research

The recent trend about the protection of the environment has led the business sector to comply with the environmental protection regulations, by adopting corresponding policies. The present thesis is therefore an attempt to understand the business factors that affect environmental sustainability. To this end, we built a model through which the best decision regarding the location of a remanufacturing center in a reverse supply chain can be made. The particularity of the model and the noticeable difference that separates it from previous studies stems from the fact that it helps to find the best solution, considering simultaneously both the financial result of a company and its environmental footprint. To investigate the above, the application of a WGP model were conducted in an inverse network of toner and ink containers, in the geographical area of Thessaly, Greece. Regarding the results of the research, we managed to identify the optimal location for the establishment of multiple remanufacturing centers, through which we achieve the optimal combined result.

Despite this, in this effort, we were faced with certain obstacles that should be mentioned. The first and most important limitation is the inability to find reliable data that respond to the case study. Specifically, if we exclude the structure of the network, which is obtained from the website of the company in question, the constants of costs and emissions were calculated and approached using historical data that we obtained from the Internet. In addition to the part of the emissions, data referring to a period three years ago is used. Also, the application of the model was conducted based on a given category of vehicle, where we did not know if the company uses it. Regarding the transfer of the returned amounts, only road routes were included, which does not correspond to reality. An additional limitation is related to the nature of the problem. In particular, the CFL problem was investigated using only the transportation costs and the construction cost to calculate the total cost. However, it would be more accurate to consider other factors also, such as additional operating expenses, taxes, etc. A final important limitation of this method is the dependence of the variables of the total cost and total emissions on the distance, which significantly affects the result.

One of the main goals of the paper is to form the basis for conducting further studies in the future. Given the rest of the results as well as the limitations we mentioned above, we have proceeded to list some extensions that we believe will significantly benefit the business community as well as the entire world. Initially, to combat an obstacle that we mentioned previously, we recommend the extension of the study using both sea and air means of transportation. This action will offer a more representative picture of reality to all the stakeholders. We also recommend the use of other factors in the calculation of the total cost. Research on the use of state or non-state subsidies, with the aim of increasing the green performance of the reverse chain, would also be of interest. Additionally, given the international nature of contemporary business activities, it would be important to investigate the impact of the transnational spread of an RL network. The application of different pricing policies, trade tariffs, and customs fees, and the use of foreign labor are some factors that can affect significantly an international RL network. In connection with the results of Chapter 2.2, it would be interesting to also expand the study to different branches from the established ones. Finally, a current issue on which the application of the model would be very constructive is the achievement of sustainability. The study on the issues of sustainability and resilience has the potential to take full advantage of the possibilities of the proposed model.

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Appendix A: WW Tables

Table 4 WW Article List

ARTICLE LIST.xlsx

Table 5 WW Concept Matrix

CONCEPT MATRIX.xlsx

Table 6 Previous Works

PREVIOUS LR.xlsx

Appendix B: WGP Model Complementary Data Tables

Table 10 Supply Points Coordinates

		Latitude	Longtitude
S1	Siakabaras Xristos	39,55931	21,76925
S2	Aktive Systems	39,55701	21,77061
S3	Mauromatis	39,42581	21,66571
S4	Media Markt	39,60629	2,24422
S5	Electronet	39,64431	22,41774
S6	Public	39,63778	22,41594
S7	Kotsovolos	39,63834	22,41513
S8	Mobibox	39,63021	22,41444
S9	Green Supermarket	39,63048	22,41436
S10	Elassona	39,98355	22,14302
S11	Computer Service	39,99333	22,62062
S12	Cleaning	39,355	22,9231
S13	Praktiker	39,36703	22,93317
S14	Barbershop	39,37297	22,93411
S15	Skiathos	39,16827	23,48682

Table 11 Facilities Coordinates

	Latitude	Longtitude
F1	39,54975	22,46834
F2	39,30536	22,39993
F3	39,58034	21,84985
F4	39,57811	22,5355
F5	39,39197	22,74042

Table 12 Distance Matrix

Facility / Supply Point	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
F1	71	71	90	9	14	11	11	12	12	68	68	61	56	55	137
F2	79	78	80	42	47	45	45	45	45	101	95	69	68	68	150
F3	10	9	29	61	56	56	56	55	55	93	106	114	113	113	195
F4	78	77	96	12	16	16	16	15	15	69	57	50	49	49	131
F5	105	104	124	40	47	44	44	44	44	99	90	21	21	21	103

Table 13 Model Mean Variables, Goals, and Weights

MTC	0,39216	**€/tkm**
ME	56,6	**g/tkm**
G1	5000000	**€**
G2	60000000	**g**
W1	0,55	
W2	0,45	

Table 14 Model Annual Capabilities and Total Construction Cost

	Capabilities	Construction Cost
F1	696	3300000
F2	936	2290000
F3	966	2020000
F4	748	3420000
F5	594	2090000

Table 15 Model Annual Supply

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Annual Supply	55	31	82	13	94	61	93	59	12	54	44	22	34	90	76

Table 17 Final CO_2 Emissions

Facility / Supply Point	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	671436,744	191975	4E+06	0	0	0	0	0	58598	6E+06	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	150047	9E+06	4E+06	8E+06	3E+06	93757	0	4E+06	225603	538836	4E+06	1E+07

Appendix C: Statistical Data

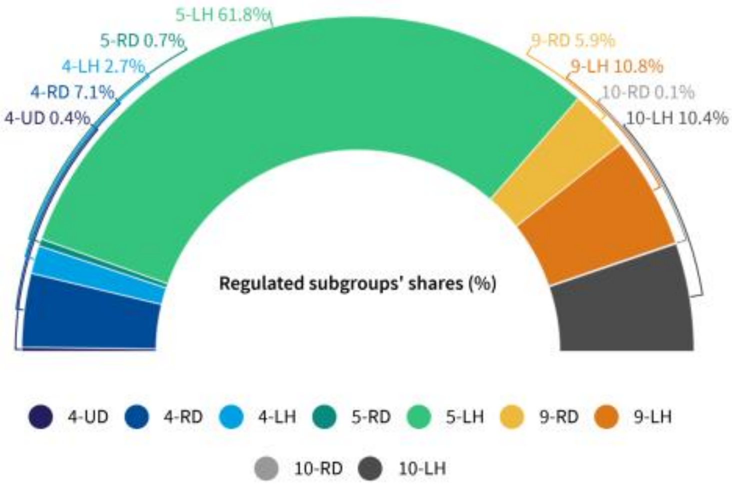

Figure 11 Vehicle Market Share [112]

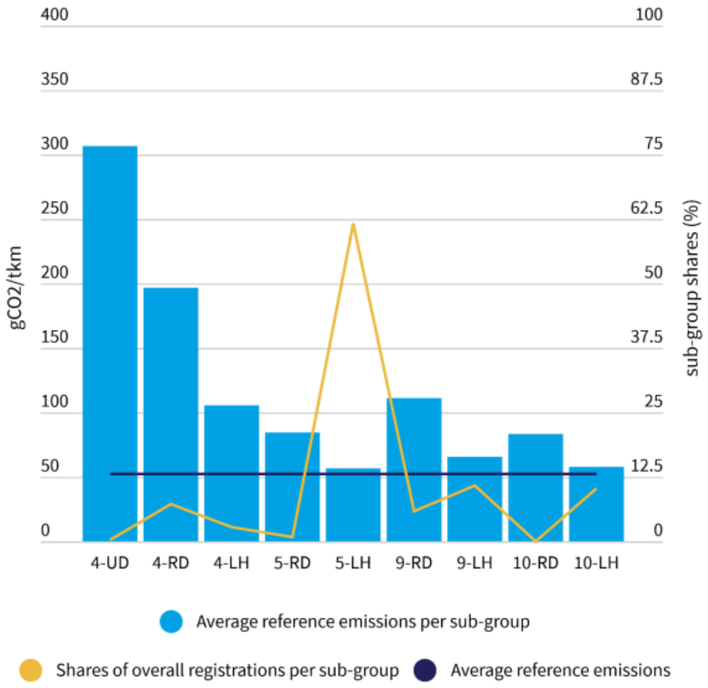

Figure 12 Vehicle CO_2 Emissions[112]

Κυρώσεις για λογοκλοπή

Η λογοκλοπή είναι ένα πολύ σοβαρό παράπτωμα. Με απόφαση της ΓΣΕΣ φοιτητής που διαπιστώνεται ότι υποπίπτει σε λογοκλοπή κατά την εκπόνηση της διπλωματικής του εργασίας αποβάλλεται από το ΠΜΣ. Εάν έχει ήδη αποφοιτήσει ανακαλείται το Μεταπτυχιακό δίπλωμα Ειδίκευσης και προωθείται το θέμα στο Δικαστικό Γραφείο του Πανεπιστημίου για την έναρξη των ανάλογων νομικών διαδικασιών.