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Practical Improvement Scenarios for an Innovative Waste-Collection Recycling Program Operating with Mobile Green Points (MGPs)

Konstantinos Tsimnadis [1], Grigorios L. Kyriakopoulos [1,2,*] and Stefanos Leontopoulos [1,*]

[1] School of Applied Arts and Sustainable Design, Hellenic Open University, Parodos Aristotelous 18, 26335 Patra, Greece; tsimnad@yahoo.gr
[2] School of Electrical and Computer Engineering, National Technical University of Athens, Heroon Polytechniou 9, Zografou Campus, 15780 Athens, Greece
* Correspondence: gregkyr@chemeng.ntua.gr (G.L.K.); sleontopoulos@uth.gr (S.L.)

Abstract: Since 2021, the prefectural authorities of the Attica Region in Greece have been operating a rewarding recycling program for the collection of clean recyclable waste in collaboration with the "Specialist Integrated Association of the Prefecture of Attica" (EDSNA, in Greek) and private contractors, called "THE GREEN CITY". This program mobilizes almost 30 mobile green points (MGPs) daily, which are self-propelled trucks that collect clean recyclable materials from citizens and businesses across the Attica Region. After one year of operation, this program has shown promising results, having more than 100,000 registered citizens and having already collected over 500 tons of clean recyclable municipal solid wastes in more than 60 municipalities of Attica. However, these promising results are accompanied by some significant financial and environmental costs. This study presents two different practical improvement scenarios for THE GREEN CITY recycling program's current situation that ensure (a) the shortening of the annual kilometers and time on the remote routes of all programs, (b) the annual fuel-cost decrease for the MGPs and (c) the annual reduction of their CO_2 emissions into the atmosphere. Afterwards, we compare these two scenarios and conclude that the "first improvement scenario with main depot decentralization" is more realistic, feasible and has a bigger total sum of positive impacts than the second one. Therefore, this study strongly suggests the implementation of the "first improvement scenario with main depot decentralization" and opens the road to future improvement scenarios for various waste-management systems or recycling programs.

Keywords: "THE GREEN CITY" recycling program; distances; fuel costs; carbon dioxide emissions; waste management

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1. Introduction

1.1. General

Currently, humanity has to face significant financial, social, energy and environmental issues. Many of these issues are related to climate change, natural-resource protection and preservation, integrated waste management and the constantly rising prices of commodities and products (e.g., fuel rising prices).

1.2. Climate Change

Climate change is mainly caused by the massive emissions of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorochemicals (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) [1,2].

According to scientific studies, the global CO_2 concentration in the atmosphere increased from 280 ppm during the pre-industrial period to over 400 ppm during the second decade of the 21st century, which is the highest CO_2 level for at least 800,000 years [2]. One ton of CO_2 can remain in the atmosphere for decades or even centuries from the moment it is emitted, causing global warming and modifying the short-term or long-term weather conditions in many regions. Consequently, climate change can strongly stress natural ecosystems (flora and fauna) and undermine human well-being in many areas of the world, both in the present and in the future [1,3]. So, climate change adaptation and mitigation should be implemented and efforts should be focused specifically on the reduction of CO_2 emissions in the atmosphere from human activities, and generally on the prioritization of sustainable development [1–3].

1.3. Natural-Resource Protection or Preservation and Integrated Waste Management

Natural-resource protection and preservation can be achieved in many cases through the implementation of integrated waste-management systems or models. For example, population growth and economic development lead to a massive annual production of solid waste and especially of municipal solid waste (MSW) [4]. MSW, normally termed as "trash" or "garbage", is mainly disposed to landfills or directly to the environment as a by-product of various human activities. Basically, waste generation encompasses activities or processes in which materials or products lose their value during their consumption, until they are considered useless. Traditionally, these exhausted and useless materials or products are either gathered together for disposal mainly to landfills (open dumps/sanitary landfills) or thrown away directly to the near environment [4]. Actually, these two waste-management practices increase public-health hazards, environmental risks, social risks and financial concerns by significantly polluting the air, water, sea and ground and by perpetuating the irrational management, spending and exploitation of precious natural resources at the cost of both the environment and humanity [4,5].

Consequently, a sustainable and efficient solution for this waste-management problem is the faithful implementation of the "3R concept", also known as the "zero waste concept" [4,5]. This concept is defined by the key words of reuse, recycling and recovery, which are closely related with the wider meanings of sustainability, innovation and competitiveness [5]. Practically, this concept can be carried out through an integrated waste-management system, which is a widely accepted approach. This approach can successfully separate and collect solid wastes, and primarily MSW, at their own source where they are generated. Afterwards, it can turn end-of-life products or materials into useful resources through the implementation of efficient reuse, recycling and recovery processes [4,5]. All these end-of-life products or materials (also known as wastes) can be reused, repaired, sold, redistributed, recycled or even recovered from the waste stream and utilized as valuable inputs, substituting the demand for additional natural resources [5]. Finally, the 3R concept represents the transition from a linear economy model to a circular economy model, where an integrated waste-management system as a tool/approach can bring significant and numerous benefits like competitiveness increase, new sources of growth, the creation of new jobs, cost savings from improved waste-management efficiency, the commercialization of innovations, a reduction in GHG emissions, public health protection, the limitation of environmental pollution (water, sea, land and air), environmental protection (flora and fauna), more efficient resource consumption, a slowdown of the s further exploitation of natural resources, and of course natural-resource protection and preservation [4,5].

1.4. Rising Commodity and Product Prices

Furthermore, rising commodity and product prices and especially rising fuel prices are responsible for a great number of social, energy and financial problems. The transportation of people and goods are major factors for social and financial development. They significantly improve the quality of life and also maintain high living standards in many societies worldwide [6]. On the other hand, the transportation of people and goods pollutes the air, degrades the environment, causes traffic congestion in urban areas, provokes health issues and demands huge amounts of non-renewable energy sources like fossil fuels (e.g., oil, natural gas, etc.). Hence, rising fuel prices directly affect economic development and planning in almost every sector of human activities, including the transportation sector [6]. According to a World Bank forecast, it was estimated that for the period 2014–2030 crude-oil prices will increase considerably, from USD 55 per barrel to almost USD 80 per barrel [7]. This increase significantly affects the variable costs of transportation, although the role of fuel costs in total freight costs differs by country, tax policy, type of shipment, and by load factors and distance [7]. As a result, rising transportation costs can severely affect the inflation of each country and increase the prices of almost every good that needs to be transported. Generally, in strong economies like that of the United Kingdom, fuel costs are amongst the highest of all operating costs that both the producers and the consumers have to face regularly [8].

Through green development and sustainability reasonable and practical approaches that can mitigate the issue of rising fuel prices have been proposed. Energy efficiency improvement is one of these and can be achieved in various ways, especially by internal combustion engines [9]. It has already been proved that there is a big potential for fuel savings and thus for energy savings in all sectors of the economy, with the transportation sector having the biggest promise among the others. Three main practical ways to achieve high fuel efficiency in the transportation sector are a) a reduction in the total distance travelled through improved routing and scheduling, b) a reduction in the total consumed fuels for the transportation of goods through the use of high-capacity trucks or double-deck trailers and c) the improvement in fuel-consumption-efficiency measuring through the sufficient training of drivers in primary-fuel efficiency measurements for vehicles, such as the MPG (miles per gallon) measurement [9]. Additionally, energy efficiency improvement reduces CO_2 emissions from engines, primarily in the transportation and industrial sectors, which operate using fossil fuels [8,9]. Therefore, improvements in fuel and energy efficiency, notably in the transportation sector, can considerably reduce many of the negative financial, social and environmental impacts of rising fuel prices [8,9]. This study presents and compares two different practical improvement scenarios for THE GREEN CITY recycling program's current situation in the region of Attica. The purpose of this study is to open the road to future improvement scenarios for various waste-management systems or recycling programs in the Attica region. The novelty of this work is found in the fact that it proposes two future decentralization scenarios of the current application of THE GREEN CITY program. The presented research is based on practical plans using mapping, geometry and geography in order to reduce the program's annual CO_2 emissions, as well as reducing the annual costs of program application to purchase fuel for its mobile green points (MGPs).

1.5. THE GREEN CITY Recycling Program

1.5.1. General Description

Since 2021, the prefectural authorities of the Attica region have been operating a rewarding recycling program for the collection of clean recyclable waste in collaboration with the "Specialist Integrated Association of the Prefecture of Attica" (EDSNA, in Greek) and private contractors, that is called "THE GREEN CITY". This initiative separately collects paper, cardboard, batteries, small electric and electronic appliances, different metals, aluminum, transparent plastic bottles for liquids and food (PET), non-transparent plastic containers (PP, PS, HDPE, LDPE, PE and PVC), edible oils, glass, and clothing and textiles, from municipal solid waste (MSW), while organic waste is excluded [10]. In practice, citizens and businesses across the prefecture of Attica are registered at "THE GREEN CITY" recycling program with the commitment to bring, on a weekly basis, their clean MSW, separated by material through source separation, to their nearest mobile green point (MGP) and without any charge from the program's concessionaires [10]. Consequently, "THE GREEN CITY", as a rewarding recycling program, makes great discounts and offers to registered citizens and businesses who correctly bring their clean and segregated MSW, for the acquisition of new products and services, mainly from big or small sponsors of the program like banks, power corporations, big retail chains, supermarkets and local shops [10].

This program can actually serve more than 3 million inhabitants across the Attica region. It mobilizes almost 30 Mobile Green Points (MGPs) daily, which are self-propelled trucks (Figure 1). Each of them can carry almost 1.2 tons of clean recyclable materials per day and has a length of about 6.5 to 8.0 m for the purpose of easily moving and parking within the densely populated municipalities of the prefecture of Attica [10]. Currently, "THE GREEN CITY" program is serving more than 100,000 registered citizens and has already collected over 500 tons of clean recyclable MSW in more than 60 municipalities of Attica [10]. Every day, from Monday to Friday, each of the MGPs visits one of these municipalities at three different central parking spots of its territory (including schools, outdoor parking, supermarkets, parks, etc.). Practically, MGPs are installed and operate at each parking spot for one or two hours in order to primarily collect separate clean recyclable waste and materials from the pre-registered citizens and businesses in the program, and secondarily to inform and register new citizens and businesses in this promising recycling initiative [11]. Here, it is worth noting that 56% of all these installation and operating spots (parking spots) across the collaborating municipalities of Attica for the MGPs, for the trucks, are placed next to recreational areas and parks, 17% of them are placed next to service hubs or educational hubs, 13% of them are placed next to large-scale infrastructures, 10% of them are placed next to commercial areas, 3% of them are placed next to food-related shops like restaurants and cafes, and the remaining 1% of them are formerly active (inactive) parking spots [11].

Figure 1. Operating mobile green point (MGP). Source: Authors' own picture.

1.5.2. THE GREEN CITY Routes

Every day, an MGP, in the form of a truck, starts from its central depot at Tavrou 50 (Athens metropolitan area) and visits three different installation and operating spots (parking spots) at the territory of each collaborating municipality of Attica for almost one or two hours per parking spot [11]. In essence, from Monday to Friday an MGP serves five different collaborating municipalities (one different municipality per day) of the same sub-area of the Attica prefecture. After the daily collection of clean recycling waste from registered citizens and businesses at all three of its installation and operating spots, the MGP returns back to its initial depot at Tavrou 50 in order to unload its cargo (separated recycling waste) [11]. Briefly, this is the description of a daily route completed by an MGP at a municipality of Attica under the organizational responsibility of "THE GREEN CITY" recycling program. So, the service of all remote routes in the sub-areas of western, eastern and northeastern Attica is a significant challenge for "THE GREEN CITY" program as its MGPs must travel the longest distances in terms of time and kilometers in order to complete them [11]. The theoretical basis of the circle methodology used in the article comes from Euclidean geometry and more specifically from the definition of the circular disk. Even more specifically, the most distant parking spots of each sub-region (West Attica, East Attica, North-East Attica) defining and forming the circumference of each circle and the remaining internal parking spots are internal points of the imaginary circular disk formed by the depicted circles in each sub-region. At the same time, the centers of the circles or imaginary circular disks are the proposed points for the installation of the future decentralized permanent parking stations for the mobile green points (MGPs) of each of the mentioned sub-regions of Attica.

In more detail, according to the Google Maps application, the total weekly calculated distance of all current routes (total round trip) in western Attica is 316 km while their total completion time is almost 344 min. Similarly, the total weekly calculated distance of all current routes (total round trip) in eastern Attica is 779 km while their total completion time is almost 702 min. Furthermore, the total weekly calculated distance of all current routes (total round trip) in northeastern Attica is 374.4 km while their total completion time is almost 398 min. As a result, the total weekly distance sum of all remote itineraries in western, eastern and northeastern Attica is 1469.4 km or 70,531.2 km annually (from the arithmetic operation 1469.4 km $\times$ 4 weeks $\times$ 12 months), while the total weekly time sum that is needed for the completion of all these remote itineraries is almost 1444 min or 69,312 min annually (from the arithmetic operation 1444 min $\times$ 4 weeks $\times$ 12 months) [11]. The workers at mobile green points (MGPs) and especially the drivers work mostly 8 h a day. However, their contract allows them to exceed the schedule and work additional hours paid (based on the Greek labor legislation) as overtime when needed. With the implementation of the first proposed measure, it is estimated that overtime will be significantly reduced and will rarely exceed the 8 h working period. However, with the implementation of the second proposed scenario, it is estimated that the working period will still be exceeded as in the current situation. For the mitigation of this situation, it is proposed that the mobile green points (MGPs) should park and run their various services, for less than one hour daily in each parking spot (about 45 min).

By taking into consideration the report of the General Secretariat of Commerce and Consumer Protection of the Greek Ministry of Development and Investment (on 11 November 2022), which stated that the average refinery fuel price in Greece was EUR 1.859 per liter of diesel, it was possible for all demanded fuel costs in the completion of all remote itineraries by the MGPs of "THE GREEN CITY" recycling program to be calculated. Specifically, all remote itineraries in western Attica demand almost EUR 3792 total annual fuel costs. All remote itineraries in eastern Attica demand almost EUR 9348 of total annual fuel costs. Additionally, all remote itineraries in northeastern Attica demand almost EUR 4492.8 of total annual fuel costs. Therefore, the total annual fuel cost sum for the completion of all remote itineraries in western, eastern and northeastern Attica by the MGPs of "THE GREEN CITY" program is EUR 17,632.8 (from the arithmetic calculation: EUR 3792 + EUR 9348 + EUR 4492.8) [11].

Finally, the total annual CO_2 emissions into the atmosphere from the MGPs of "THE GREEN CITY" recycling program were estimated during the coverage of all remote routes in western, eastern and northeastern Attica. According to cross-national data and information from both the European Environment Agency (EEA) and the United States Environmental Protection Agency (EPA), an MGP as a small van that is manufactured by the IVECO automobile manufacturer with the trade name IVECO DAILY 35S18 releases almost 5,566,656 g of CO_2 or 5567 kg of CO_2 into the atmosphere annually during the completion of all remote routes in western Attica. This CO_2 emission value is specifically for the distance travelled. Similarly, an IVECO DAILY 35S18 MGP releases annually almost 13,722,864 g of CO_2 or 13,723 kg of CO_2 into the atmosphere during the completion of all remote routes in eastern Attica. Furthermore, an MGP of this type releases annually almost 6,595,430.4 g of CO_2 or 6595 kg of CO_2 into the atmosphere during the completion of all remote routes in northeastern Attica. So, the total annual CO_2 emissions sum into the atmosphere from the MGPs of "THE GREEN CITY" recycling program during the coverage of all remote routes in western, Eastern and Northeastern Attica is 25,884,950.4 g of CO_2 or 25,885 kg of CO_2 (from the arithmetic calculation 5567 kg of CO_2 + 13,723 kg of CO_2 + 6595 kg of CO_2) [11].

2. Materials and Methods

2.1. Methodology of Calculating Remote-Route Distances

Initially, this study calculated the distance of each remote route of "THE GREEN CITY" recycling program carried out in western, eastern and northeastern Attica inside the framework of the "first improvement scenario with main depot decentralization" (hereafter mentioned simply as the "first improvement scenario"). In this framework, a decentralization of the main depot for the MGPs at Tavrou 50 (Figure 2) to three different (Figure 3) depots in the three sub-areas of western, eastern and northeastern Attica is proposed. Therefore, for the completion of their daily remote routes, the MGPs of "THE GREEN CITY" recycling program travel their longest distances in terms of time and kilometers from each of their decentralized depots, which is their daily point of departure towards their final destination (daily municipal service).

In essence, Google Maps was deployed to propose and calculate the optimal daily and weekly time and kilometer distances of all remote routes of "THE GREEN CITY" recycling program in the first improvement scenario (Figures 4–6). Each of these distances was estimated to start from one of the following three defined decentralized depots of an Attica sub-area (Figure 3) and to end up at the designated service points for citizens and businesses (by the MGPs) in a municipal territory of the same Attica sub-area. For example, an MGP has to cover a daily distance from its decentralized depot in western Attica to its service points in a municipal territory in western Attica. The same condition applies for each of all distances in eastern and northeastern Attica accordingly. In this study, each of these distances was intentionally multiplied by the number "2", i.e., $\times 2$, in order to derive the round-trip total time and kilometer distance that was traveled by each MGP of "THE GREEN CITY" program to each remote municipality in the Attica prefecture (Table 1).

Similarly, this study calculated the distance of each merged remote route of "THE GREEN CITY" recycling program that was carried out in western, eastern and northeastern Attica inside the framework of the "second improvement scenario with main depot decentralization and the merge of neighboring remote routes" (hereafter mentioned simply as the "second improvement scenario"). The "second improvement scenario for the "THE GREEN CITY" program proposes both the decentralization of the MGPs' central depot at Tavrou 50 to three different depots in western, eastern and northeastern Attica (one depot per each remote Attica sub-area), and the merging of each two selected neighboring remote routes in these sub-areas into one unified remote route. Actually, this "second improvement scenario" is an expansion of the first improvement scenario. Essentially, each of these three depots will be placed almost in the center of all installation and operating spots (parking spots) for the MGPs in each sub-area of the Attica prefecture, as it is clearly described in Figure 3. The main difference between the first and the second improvement scenario for the "THE GREEN CITY" recycling program is the fact that the latter (second improvement scenario) includes eight remote routes in total for serving the recycling needs of western, eastern and northeastern Attica instead of sixteen (16) remote routes, which are included in the first improvement scenario.

Table 1. Time and kilometer distances of "THE GREEN CITY" program in western Attica, in eastern Attica and in northeastern Attica under the first improvement scenario framework.

Western Attica (First Scenario)		
Destination	**Time (Minutes)**	**Distance (Kilometers)**
Megara	27	30.3
	54	60.6
Mandra—Eidyllia	55	51
	110	102
Elefsina	26	17.1
	52	34.2
Aspropyrgos	25	18.3
	50	36.6
Total	133	116.7
	266	233.4
Eastern Attica (First Scenario)		
Destination	**Time (min)**	**Distance (km)**
Pallini	27	25
	54	50
Rafina—Pikermi	36	33.1
	72	66.2
Paiania	17	17
	34	34
Kropia	23	18.6
	46	37.2
Spata—Artemida	31	26.7
	62	53.4
Markopoulo	14	10.5
	28	21
Saronikos	30	24.2
	60	48.4
Lavreotiki	24	27.8
	48	55.6
Total	202	182.9
	404	365.8
Northeastern Attica (First Scenario)		
Destination	**Time (min)**	**Distance (km)**
Oropos	36	28.4
	72	56.8
Marathon	70	48.7
	140	97.4
Dionysos	19	9.5
	38	19
Penteli	43	34.4
	86	68.8
Total	168	121
	336	242
	One-Way Trip	
	Round Trip	

Google Maps was deployed again to propose and calculate the daily and weekly time and kilometer optimum distances of all merged remote routes of "THE GREEN

CITY" recycling program in the second improvement scenario (Figures 7–9). Each of these distances was estimated to start from one of the following three defined decentralized depots of an Attica sub-area (Figure 3), to then cover the designated service points for citizens and businesses (by the MGPs) in the first municipal territory in the same Attica sub-area, then afterwards to cover the designated service points for citizens and businesses in a second neighboring municipal territory in the same Attica sub-area, and finally to end up back at its initial decentralized depot. For example, an MGP has to cover a daily distance from its decentralized depot in western Attica to its first municipal territory in western Attica, then from its first municipal territory in western Attica to its second neighboring municipal territory in western Attica and lastly from its second municipal territory to its initial decentralized depot. The same condition applies for each of all merged distances in eastern and northeastern Attica accordingly (Table 2).

Table 2. Time and kilometer distances of "THE GREEN CITY" program in western Attica, in eastern Attica and in northeastern Attica under the second improvement scenario framework.

Western Attica (Second Scenario)		
Destination	**Time (min)**	**Distance (km)**
Megara and Mandra—Eidyllia *	124	120
Elefsina and Aspropyrgos *	53	39.9
Total	177	159.9
Eastern Attica (Second scenario)		
Destination	**Time (min)**	**Distance (km)**
Pallini and Rafina—Pikermi *	80	59.2
Paiania and Spata—Artemida *	63	48.1
Markopoulo and Kropia *	55	43.1
Lavreotiki and Saronikos *	76	66.6
Total	274	217
Northeastern Attica (Second scenario)		
Destination	**Time (min)**	**Distance (km)**
Marathon and Oropos *	139	109
Penteli and Dionysos *	82	51.3
Total	221	161.3

* Round-trip distances.

2.2. Improvement Scenarios for THE GREEN CITY Recycling Program

Currently, all remote itineraries of "THE GREEN CITY" recycling program in western, eastern and northeastern Attica start from the central depot address of the MGPs at Tavrou 50 (Athens metropolitan area) and end up at the designated service points for citizens and businesses (by the MGPs) in the territory of each municipality in the Attica prefecture (Figure 2).

2.2.1. First Improvement Scenario with Main Depot Decentralization

This "first improvement scenario with main depot decentralization" for the "THE GREEN CITY" program proposes the decentralization of the MGPs' central depot at Tavrou 50 to three different depots in western, eastern and northeastern Attica (one depot per each remote Attica sub-area). Actually, each of these three depots will be placed almost in the center of all installation and operating spots (parking spots) for the MGPs in each sub-area of the Attica prefecture. Naturally, this placement will be performed on vacant (without any active human activity) and directly accessible land. One practical way for a project manager to find the center of these parking spots is to draw a circle on the map, where its perimeter will be defined by the most distant parking spots of each sub-area of Attica. Substantially, the center of each circle will represent the center of all installation and operating spots (parking spots) for the MGPs in each sub-area of the Attica region.

Figure 3 reveals this concept on a map of the Attica region in a more enlightening and comprehensive way. Therefore, the comparison of Figures 2 and 3 shows the positioning differences of the depots for the MGPs between the current situation and the first proposed improvement scenario.

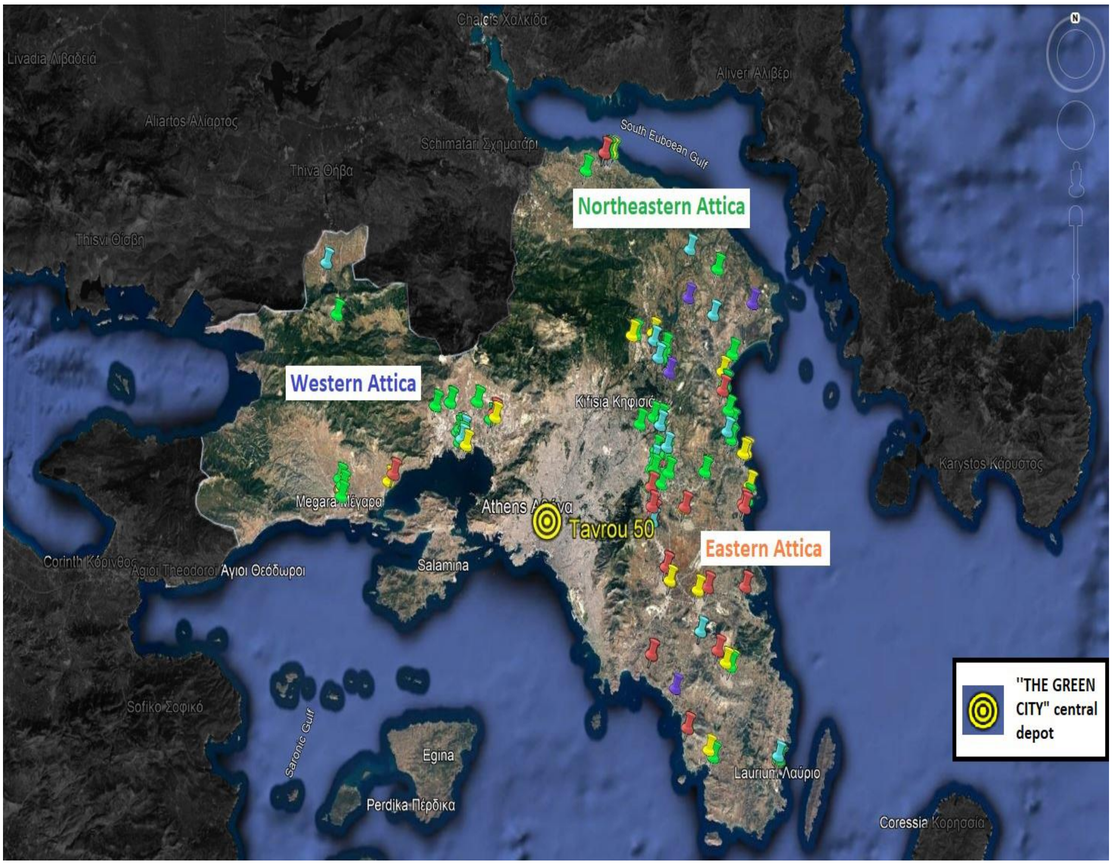

Figure 2. Current depot and remote-parking-spots positioning for the mobile green points (MGPs) of "THE GREEN CITY" recycling program, Google Earth Pro 2022. Source: Authors' own study.

First Improvement Scenario Distances

According to the Google Maps application, which was deployed to calculate the weekly time and kilometer distances of each remote route of "THE GREEN CITY" recycling program in the first improvement scenario, the proposed decentralization of the main depot for the MGPs at Tavrou 50, to three different depots in the three sub-areas of western, eastern and northeastern Attica, will considerably reduce almost every remote itinerary by its size and duration. So, every one of them (remote itinerary) will start from each sub-area's decentralized depot and will end up at the designated service points for citizens and businesses (by the MGPs) in the territory of each municipality in the Attica region (Figures 4–6).

Specifically, the total weekly calculated distance of all remote routes (total round trip) in western Attica will be 233.4 km while their total completion time will be almost 266 min (Table 1). Similarly, the total weekly calculated distance of all remote routes (total round trip) in eastern Attica will be 365.8 km while their total completion time will be almost 404 min (Table 1). Furthermore, the total weekly calculated distance of all remote routes (total round trip) in northeastern Attica will be 242 km while their total completion time will be almost 336 min (Table 1). As a result, the total weekly distance sum of all remote itineraries in this first improvement scenario will be 841.2 km or 40,377.6 km annually (from the arithmetic calculation 841.2 km × 4 weeks × 12 months) while the total weekly time sum that will be needed for the completion of all these remote itineraries will be almost 1006 min or 48,288 min annually (from the arithmetic calculation 1006 min × 4 weeks × 12 months).

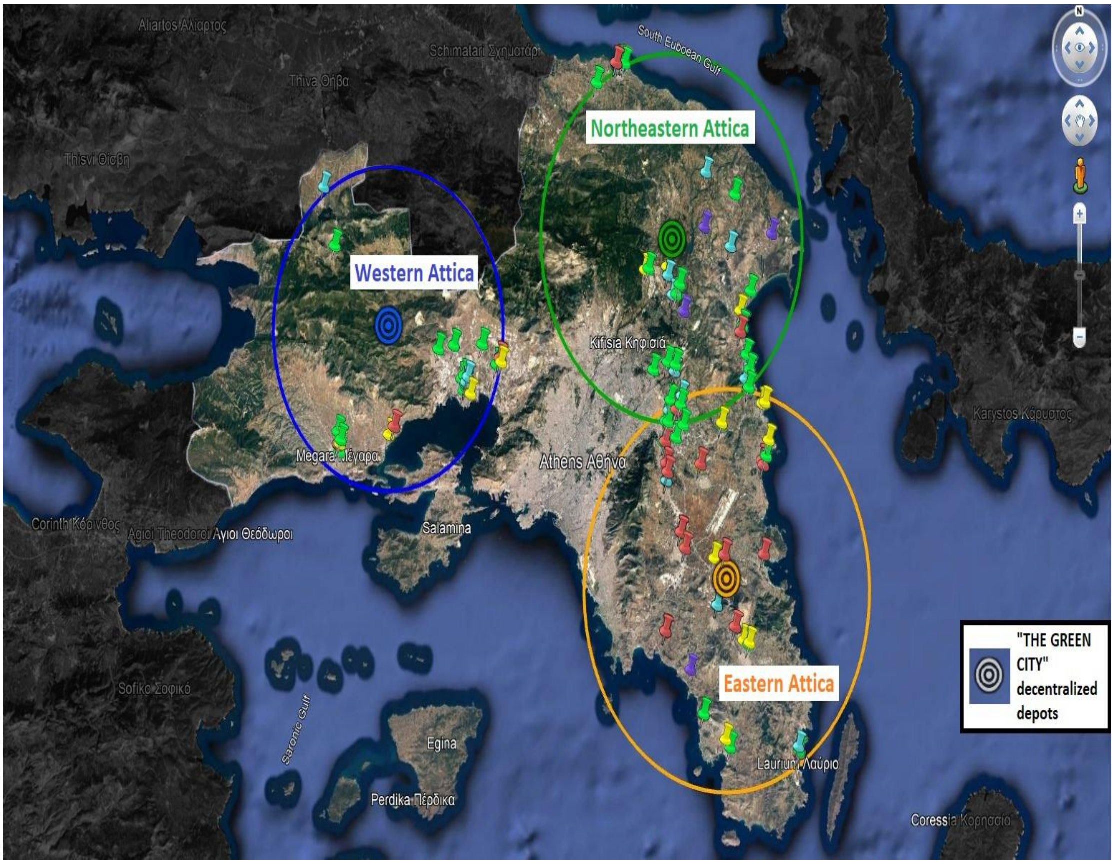

Figure 3. New decentralized depot positioning for the mobile green points (MGPs) of "THE GREEN CITY" recycling program according to the first improvement scenario, Google Earth Pro 2022. Source: Authors' own study.

Fuel Cost for the MGPs in the First Improvement Scenario

If the official reports and estimations of the European Environment Agency (EEA) and the United States Environmental Protection Agency (EPA) for the year 2020 are taken into account, then it can be concluded that an IVECO DAILY 35S18 (as an MGP) emits A1 = 309 g CO_2/km when it is only carrying its basic equipment, while it emits A2 = 425 g CO_2/km when it is filled with collected clean recyclable materials [12]. Furthermore, an IVECO MGP produces approximately 10,180 g of CO_2 per gallon of diesel fuel, which is equivalent to B = 2687.52 g of CO_2 per liter of diesel [11,13]. Additionally, by taking into consideration the official report of the General Secretariat of Commerce and Consumer Protection of the Greek Ministry of Development and Investment (on 11 November 2022) that the average refinery fuel price in Greece was C = EUR 1.859 per liter of diesel and by combining it with the aforementioned values, it can be calculated that an IVECO MGP consumes D1 = 0.115 L of diesel/km when it is traveling empty, while it consumes D2 = 0.158 L of diesel/km when it is traveling with full cargo (of collected recyclable materials) [14]. Finally, it was derived that an IVECO MGP spends almost P1 = 0.21 EUR /km for fuels when it is traveling empty, while it spends P2 = 0.29 EUR /km for fuels when it is traveling fully loaded (with collected recyclable materials) [11].

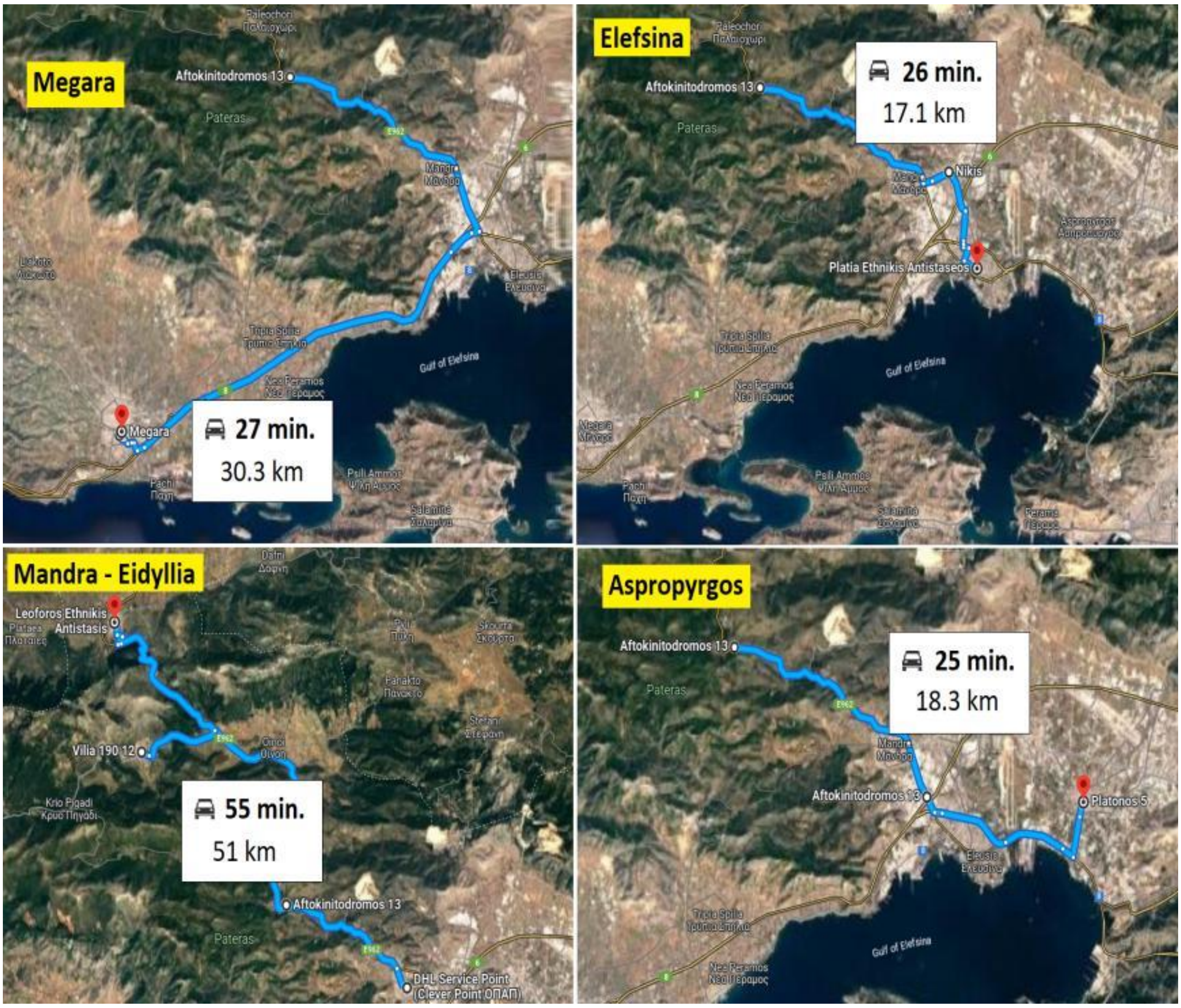

Figure 4. Time and kilometer distances of "THE GREEN CITY" program in western Attica according to the first improvement scenario, Google Maps 2022. Source: Authors' own study.

Subsequently, it can be assumed that for each serviced route of "THE GREEN CITY" recycling program in the remote municipalities of West, East and Northeast Attica within the framework of the first improvement scenario, the MGPs (as small vans manually driven) travel their transition distance unloaded, and their return distance, from their itinerary destination to their decentralized local depot, fully loaded. In consideration of this assumption, the MGPs show different fuel-consumption profiles during the transition to their daily service destination and when returning back to their decentralized local depot. It is also stipulated that each of the remote routes in western, eastern and northeastern Attica takes place once a week, and thus, four times a month. Therefore, in this first improvement scenario the following calculations were applied for the estimation of the total annual fuel cost for the MGPs in the western Attica remote itineraries:

L1 = (Xwg × P1) × 4 = (116.7 km × 0.21 EUR /km) × 4 weeks = 98.03 EUR total monthly fuel cost to travel the transit distance of all remote routes in western Attica within the framework of the first improvement scenario, where

Xwg = Xwr: Total transit distance of all MGP routes in western Attica within the framework of the first improvement scenario (Figure 4 and Table 1).

Figure 5. Time and kilometer distances of "THE GREEN CITY" program in eastern Attica according to the first improvement scenario, Google Maps 2022. Source: Authors' own study.

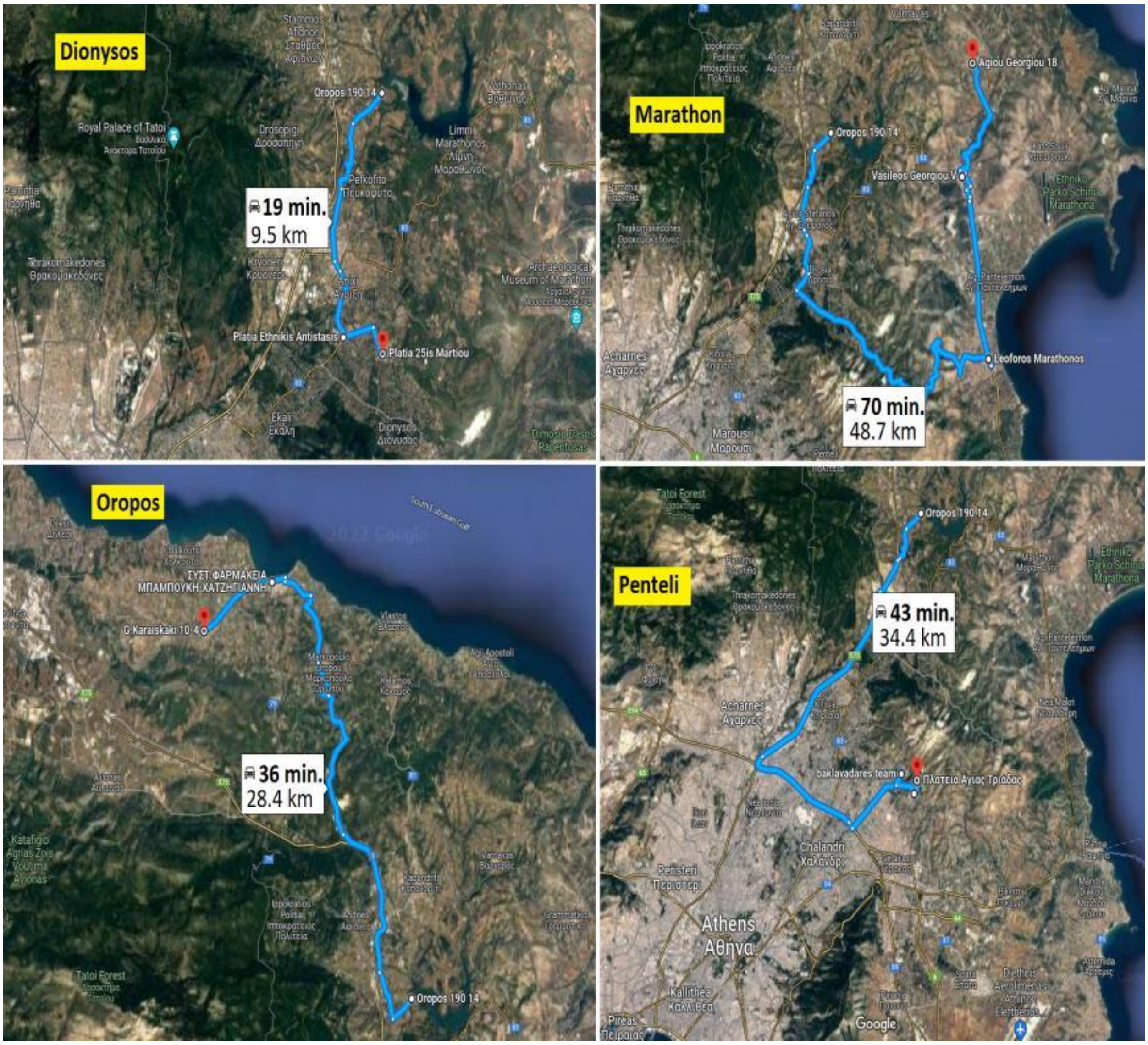

Figure 6. Time and kilometer distances of "THE GREEN CITY" program in northeastern Attica according to the first improvement scenario, Google Maps 2022. Source: Authors' own study.

P1: Fuel consumption of an empty moving IVECO MGP.

L2 = (Xwr × P2) × 4 = (116.7 km × 0.29 EUR /km) × 4 weeks = 135.37 EUR total monthly fuel cost to travel the return distance of all remote routes in western Attica within the framework of the first improvement scenario, where

Xwr = Xwg: The total return distance of all MGP routes in western Attica within the framework of the first improvement scenario (Figure 4 and Table 1).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover,

LTw = (L1 + L2) × 12 = (98.03 EUR + 135.37 EUR) × 12 months = 2800.8 EUR total annual fuel cost for handling all the remote routes of western Attica by the MGPs within the framework of the first improvement scenario.

Furthermore, the following calculations are applied for the estimation of the total annual fuel cost for the MGPs in the eastern Attica remote itineraries:

L3 = (Xeg × P1) × 4 = (182.9 km × 0.21 EUR /km) × 4 weeks = 153.64 EUR total monthly fuel cost to travel the transit distance of all remote routes in eastern Attica within the framework of the first improvement scenario, where

Xeg = Xer: Total transit distance of all MGP routes in eastern Attica within the framework of the first improvement scenario (Figure 5 and Table 1).

P1: Fuel consumption of an empty moving IVECO MGP.

L4 = (Xer × P2) × 4 = (182.9 km × 0.29 EUR /km) × 4 weeks = 212.16 EUR total monthly fuel cost to travel the return distance of all remote routes in eastern Attica within the framework of the first improvement scenario, where

Xer = Xeg: The total return distance of all MGP routes in eastern Attica within the framework of the first improvement scenario (Figure 5 and Table 1).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover:

LTe = (L3 + L4) × 12 = (153.64 EUR + 212.16 EUR) × 12 months = 4389.6 EUR total annual fuel cost for handling all the remote routes of eastern Attica by the MGPs within the framework of the first improvement scenario.

In addition, the following calculations are applied for the estimation of the total annual fuel cost for the MGPs in the northeastern Attica remote itineraries:

L5 = (Xneg × P1) × 4 = (121 km × 0.21 EUR /km) × 4 weeks = 101.64 EUR total monthly fuel cost to travel the transit distance of all remote routes in northeastern Attica within the framework of the first improvement scenario, where:

Xneg = Xner: Total transit distance of all MGP routes in northeastern Attica within the framework of the first improvement scenario (Figure 6 and Table 1).

P1: Fuel consumption of an empty moving IVECO MGP.

L6 = (Xner × P2) × 4 = (121 km × 0.29 EUR /km) × 4 weeks = 140.36 EUR total monthly fuel cost to travel the return distance of all remote routes in northeastern Attica within the framework of the first improvement scenario, where

Xner = Xneg: The total return distance of all MGP routes in northeastern Attica within the framework of the first improvement scenario (Figure 6 and Table 1).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover,

LTne = (L5 + L6) × 12 = (101.64 EUR + 140.36 EUR) × 12 months = 2904 EUR total annual fuel cost for handling all the remote routes of northeastern Attica by the MGPs within the framework of the first improvement scenario.

Conclusively, the total annual fuel cost for the completion of all remote itineraries in western, eastern and northeastern Attica combined within the framework of the first improvement scenario is

LT = LTw + LTe + LTne = EUR 2800.8 + EUR 4389.6 + EUR 2904 = 10,094.4 EUR/year

CO_2 Emissions into the Atmosphere from the MGPs in the First Improvement Scenario

As it has already been mentioned and confirmed by the EEA through a worldwide harmonized light-vehicle test procedure (WLTP, a testing procedure used to find out the real-world fuel economy and CO_2 emissions of a vehicle), an IVECO DAILY 35S18 MGP emits A1 = 309 g CO_2/km when it only carries its basic equipment, while it releases A2 = 425 g CO_2/km when it is filled with collected clean recyclable materials [12]. Primarily, for the calculation of CO_2 emissions that are released from the MGPs into the atmosphere, the following calculations are made, taking into account all the aforementioned distances in western Attica, in eastern Attica and in northeastern Attica that have already been presented in Section 2.1. and which were consequently adopted. Therefore, in this first improvement scenario, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of western Attica remote itineraries:

E1 = (Xwg × A1) × 4 = (116.7 km × 309 g CO_2/km) × 4 weeks = 144,241.2 g CO_2 total monthly emissions that are released into the atmosphere during the transition distance of all remote routes in western Attica within the framework of the first improvement scenario, where

Xwg = Xwr: Total transit distance of all MGP routes in western Attica within the framework of the first improvement scenario (Figure 4 and Table 1).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

E2 = (Xwr × A2) × 4 = (116.7 km × 425 g CO_2/km) × 4 weeks = 198,390 g CO_2 total monthly emissions that are released into the atmosphere during the return distance of all remote routes in western Attica within the framework of the first improvement scenario, where

Xwr = Xwg: The total return distance of all MGP routes in western Attica within the framework of the first improvement scenario (Figure 4 and Table 1).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

ETw = (E1 + E2) × 12 = (144,241.2 g CO_2 + 198,390 g CO_2) × 12 months = 4,111,574.4 g CO_2 or 4112 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of western Attica remote routes within the framework of the first improvement scenario.

Furthermore, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of eastern Attica remote itineraries:

E3 = (Xeg × A1) × 4 = (182.9 km × 309 g CO_2/km) × 4 weeks = 226,064.4 g CO_2 total monthly emissions that are released into the atmosphere during the transition distance of all remote routes in eastern Attica within the framework of the first improvement scenario, where

Xeg = Xer: Total transit distance of all MGP routes in eastern Attica within the framework of the first improvement scenario (Figure 5 and Table 1).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

E4 = (Xer × A2) × 4 = (182.9 km × 425 g CO_2/km) × 4 weeks = 310,930 g CO_2 total monthly emissions that are released into the atmosphere during the return distance of all remote routes in eastern Attica within the framework of the first improvement scenario, where

Xer = Xeg: The total return distance of all MGP routes in eastern Attica within the framework of the first improvement scenario (Figure 5 and Table 1).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

ETe = (E3 + E4) × 12 = (226,064.4 g CO_2 + 310,930 g CO_2) × 12 months = 6,443,932.8 g CO_2 or 6444 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of eastern-Attica remote routes within the framework of the first improvement scenario.

In addition, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of northeastern Attica remote itineraries:

E5 = (Xneg × A1) × 4 = (121 km × 309 g CO_2/km) × 4 weeks = 149,556 g CO_2 total monthly emissions that are released into the atmosphere during the transition distance of all remote routes in northeastern Attica within the framework of the first improvement scenario, where

Xneg = Xner: Total transit distance of all MGP routes in northeastern Attica within the framework of the first improvement scenario (Figure 6 and Table 1).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

E6 = (Xner × A2) × 4 = (121 km × 425 g CO_2/km) × 4 weeks = 205,700 g CO_2 total monthly emissions that are released into the atmosphere during the return distance of all remote routes in northeastern Attica within the framework of the first improvement scenario, where

Xner = Xneg: The total return distance of all MGP routes in northeastern Attica within the framework of the first improvement scenario (Figure 6 and Table 1).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

ETne = (E5 + E6) × 12 = (149,556 g CO_2 + 205,700 g CO_2) × 12 months = 4,263,072 g CO_2 or 4263 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of northeastern Attica remote routes within the framework of the first improvement scenario.

Conclusively, the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of all remote itineraries in western, eastern and northeastern Attica combined within the framework of the first improvement scenario are

ET = ETw + ETe + ETne = 4,111,574.4 g CO_2 + 6,443,932.8 g CO_2 + 4,263,072 g CO_2 = 14,818,579.2 g CO_2/year or 14,819 kg of CO_2/year.

2.2.2. Second Improvement Scenario with Main Depot Decentralization and the Merging of Neighboring Remote Routes

The second improvement scenario (fully named as: "second improvement scenario with main depot decentralization and the merge of neighboring remote routes") for "THE GREEN CITY" program proposes both the decentralization of the MGPs' central depot at Tavrou 50 to three different depots in western, eastern and northeastern Attica (one depot per each remote Attica sub-area) and the merging of every two selected neighboring remote routes, in these sub-areas, into one unified remote route. Actually, this second improvement scenario is an expansion of the first improvement scenario (fully named as: "first improvement scenario with main depot decentralization"). Substantially, each of these three depots will be placed almost in the center of all installation and operating spots (parking spots) for the MGPs in each sub-area of the Attica prefecture as it is clearly described in Figure 3. The main difference between the first and the second improvement scenario for the "THE GREEN CITY" recycling program is the fact that the last one (second improvement scenario) includes eight remote routes in total for serving the recycling needs of western, eastern and northeastern Attica instead of sixteen remote routes, which are included in the first improvement scenario. So, the aforementioned depot decentralization combined with the merging of all remote routes in western, eastern and northeastern Attica, from sixteen (16) into eight (8) remote routes in total, will significantly shorten the time and kilometer distances for the MGPs in these distant sub-areas within the framework of the second improvement scenario (Figures 7–9).

Second-Improvement-Scenario Distances

Actually, Google Maps has confirmed the reduction in time and kilometer distances of almost every remote itinerary in western, eastern and northeastern Attica within the framework of the second improvement scenario. Specifically, the total weekly calculated distance of all remote routes (total round trip) in western Attica will be 159.9 km while their total completion time will be almost 177 min (Table 2). Similarly, the total weekly calculated distance of all remote routes (total round trip) in eastern Attica will be 217 km while their total completion time will be almost 274 min (Table 2). Furthermore, the total weekly calculated distance of all remote routes (total round trip) in northeastern Attica will be 160.3 km while their total completion time will be almost 221 min (Table 2). As a result, the total weekly distance sum of all remote itineraries in this second improvement scenario will be 537.2 km or 25,785.6 km annually (from the arithmetic calculation 537.2 km × 4 weeks × 12 months) while the total weekly time sum that will be needed for the completion of all these remote itineraries will be almost 672 min or 32,256 min annually (from the arithmetic calculation 672 min × 4 weeks × 12 months).

Figure 7. Time and kilometer distances of "THE GREEN CITY" program in western Attica according to the second improvement scenario, Google Maps 2022. Source: Authors' own study.

Fuel Cost for the MGPs in the Second Improvement Scenario

Here, in this second improvement scenario, the same reports and estimations of the European Environment Agency (EEA) and the United States Environmental Protection Agency (EPA) for the year 2020 are taken into account, as they were taken into account in the first improvement scenario. So, an IVECO DAILY 35S18 (as an MGP) emits A1 = 309 g CO_2/km when it only carries its basic equipment, while it emits A2 = 425 g CO_2/km when it is filled with collected clean recyclable materials and A3 = 367 g CO_2/km when it is half-filled with collected clean recyclable materials (from the average of A1 and A2) [12]. Furthermore, an IVECO MGP produces approximately 10,180 g of CO_2 per gallon of diesel fuel, which is equivalent to B = 2687.52 g of CO_2 per liter of diesel [11,13]. Additionally, by taking into consideration the official report of the General Secretariat of Commerce and Consumer Protection of the Greek Ministry of Development and Investment (on 11 November 2022) that the average refinery fuel price in Greece was C = EUR 1.859 per liter of diesel and by combining it with the aforementioned values, it was calculated that an IVECO MGP consumes D1 = 0.115 L of diesel/km when it is traveling empty, while it consumes D2 = 0.158 L of diesel/km when it is traveling with full cargo (of collected recyclable materials) [14]. Finally, it was derived that an IVECO MGP spends almost P1 = 0.21 EUR/km for fuels when it is traveling empty, while it spends P2 = 0.29 EUR /km for fuels when it is traveling fully loaded (with collected recyclable materials) and P3 = 0.25 EUR /km for fuels when it is traveling half-loaded (from the average of P1 and P2) [11].

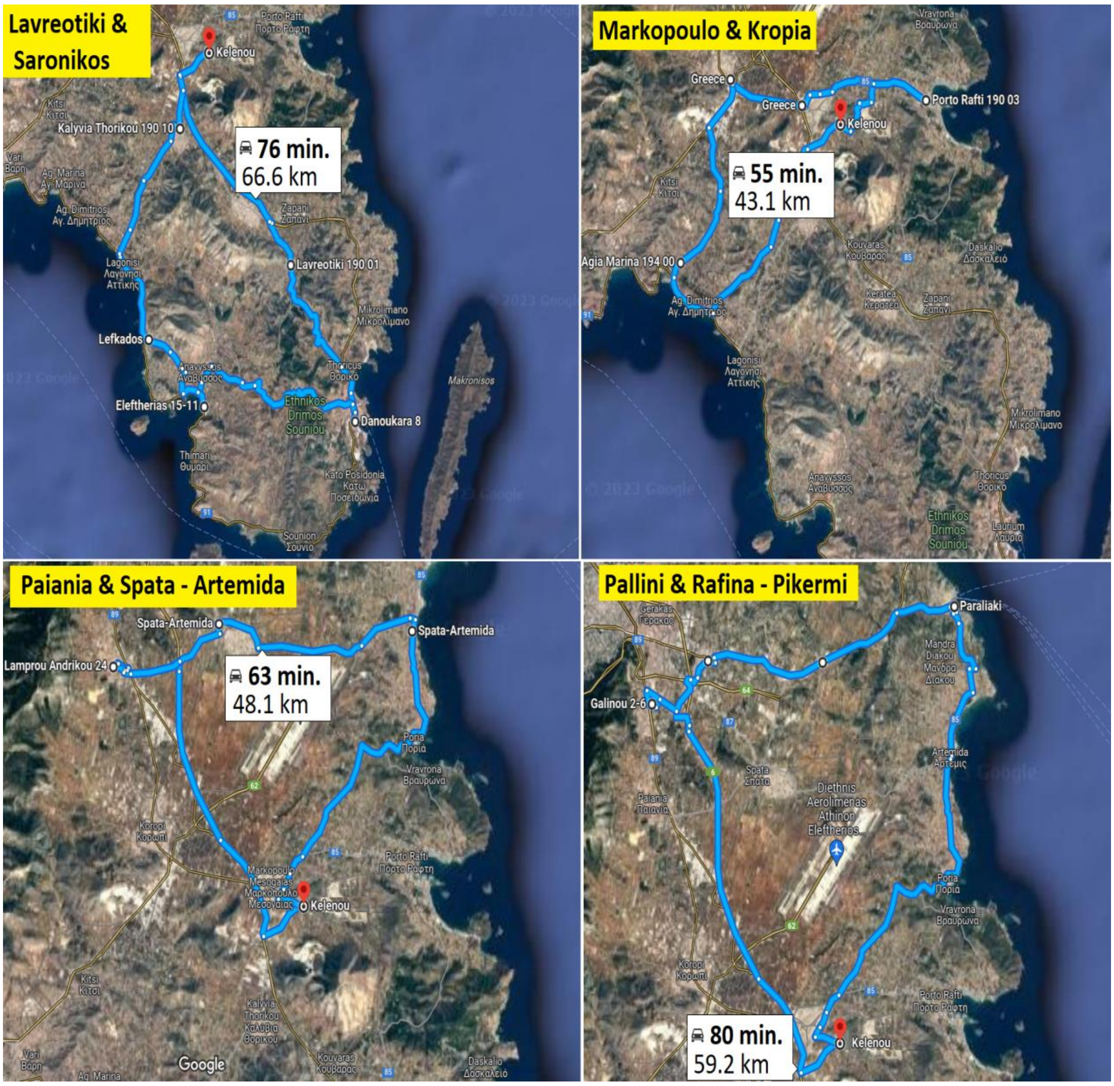

Figure 8. Time and kilometer distances of "THE GREEN CITY" program in eastern Attica according to the second improvement scenario, Google Maps 2022. Source: Authors' own study.

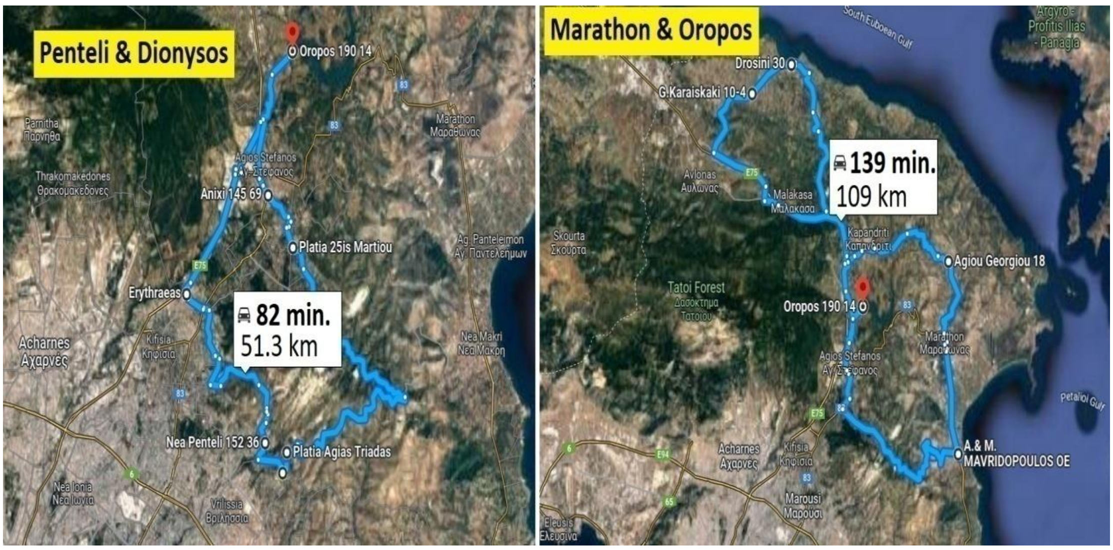

Figure 9. Time and kilometer distances of "THE GREEN CITY" program in northeastern Attica according to the second improvement scenario, Google Maps 2022. Source: Authors' own study.

Subsequently, it is assumed that for each serviced route of “THE GREEN CITY” recycling program in the remote municipalities of West, East and Northeast Attica within the framework of the second improvement scenario, the MGPs (as small vans being manually driven) travel their transition distance from their decentralized local depot to their first remote municipal destination of their new merged remote itineraries unloaded. Then, the MGPs move from their first remote municipal destination to their second remote municipal destination of their new merged remote itineraries half-loaded. Lastly, it is acknowledged that the MGPs complete their return distance, from their second remote municipal destination to their decentralized local depot, fully loaded. In consideration of all these assumptions, the MGPs show different fuel-consumption profiles during their daily transition to their first municipal destination (1/3 of the total daily distance), during their next daily transition to their second municipal destination (2/3 of the total daily distance) and when returning back to their decentralized local depot (3/3 of the total daily distance). It is also stipulated that each of the merged remote routes in western, eastern and northeastern Attica takes place once a week, thus, four times a month. Therefore, in this second improvement scenario, the following calculations are applied for the estimation of the total annual fuel cost for the MGPs in the western-Attica merged remote itineraries:

$L1' = (Xwd/3 \times P1) \times 4 = (159.9/3 \text{ km} \times 0.21 \text{ EUR /km}) \times 4 \text{ weeks} = 44.77$ EUR total monthly fuel cost for the MGPs to travel all transit distances from their decentralized local depot to their first remote municipal destinations in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

P1: Fuel consumption of an empty moving IVECO MGP.

$L3' = (Xwd/3 \times P3) \times 4 = (159.9/3 \text{ km} \times 0.25 \text{ EUR /km}) \times 4 \text{ weeks} = 53.3$ EUR total monthly fuel cost for the MGPs to travel all transit distances from their first remote municipal destinations to their second remote municipal destinations in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

P3: Fuel consumption of a half-loaded (with collected recyclable materials) moving IVECO MGP.

$L2' = (Xwd/3 \times P2) \times 4 = (159.9/3 \text{ km} \times 0.29 \text{ EUR/km}) \times 4 \text{ weeks} = 61.83$ EUR total monthly fuel cost for the MGPs to travel all return distances from their second remote municipal destinations back to their decentralized local depot in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover,

$LTw' = (L1' + L3' + L2') \times 12 = (44.77 \text{ EUR} + 53.3 \text{ EUR} + 61.83 \text{ EUR}) \times 12 \text{ months} = 1918.8$ EUR total annual fuel cost for handling all merged remote routes of western Attica by the MGPs within the framework of the second improvement scenario.

Furthermore, the following calculations are applied for the estimation of the total annual fuel cost for the MGPs in eastern Attica merged remote itineraries:

$L4' = (Xed/3 \times P1) \times 4 = (217/3 \text{ km} \times 0.21 \text{ EUR /km}) \times 4 \text{ weeks} = 60.76$ EUR total monthly fuel cost for the MGPs to travel all transit distances from their decentralized local depot to their first remote municipal destinations in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

P1: Fuel consumption of an empty moving IVECO MGP.

$L5' = (Xed/3 \times P3) \times 4 = (217/3\ km \times 0.25\ EUR\ /km) \times 4\ weeks = 72.33\ EUR$ total monthly fuel cost for the MGPs to travel all transit distances from their first remote municipal destinations to their second remote municipal destinations in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

P3: Fuel consumption of a half loaded (with collected recyclable materials) moving IVECO MGP.

$L6' = (Xed/3 \times P2) \times 4 = (217/3\ km \times 0.29\ EUR\ /km) \times 4\ weeks = 83.91\ EUR$ total monthly fuel cost for the MGPs to travel all return distances from their second remote municipal destinations back to their decentralized local depot in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover,

$LTe' = (L4' + L5' + L6') \times 12 = (60.76\ EUR + 72.33\ EUR + 83.91\ EUR) \times 12\ months = 2604\ EUR$ total annual fuel cost for handling all merged remote routes of eastern Attica by the MGPs within the framework of the second improvement scenario.

In addition, the following calculations are applied for the estimation of the total annual fuel cost for the MGPs in northeastern Attica merged remote itineraries:

$L7' = (Xned/3 \times P1) \times 4 = (160.3/3\ km \times 0.21\ EUR\ /km) \times 4\ weeks = 44.88\ EUR$ total monthly fuel cost for the MGPs to travel all transit distances from their decentralized local depot to their first remote municipal destinations in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

P1: Fuel consumption of an empty moving IVECO MGP.

$L8' = (Xned/3 \times P3) \times 4 = (160.3/3\ km \times 0.25\ EUR\ /km) \times 4\ weeks = 53.43\ EUR$ total monthly fuel cost for the MGPs to travel all transit distances from their first remote municipal destinations to their second remote municipal destinations in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

P3: Fuel consumption of a half loaded (with collected recyclable materials) moving IVECO MGP.

$L9' = (Xned/3 \times P2) \times 4 = (160.3/3\ km \times 0.29\ EUR\ /km) \times 4\ weeks = 61.98\ EUR$ total monthly fuel cost for the MGPs to travel all return distances from their second remote municipal destinations back to their decentralized local depot in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

P2: Fuel consumption of a fully loaded (with collected recyclable materials) moving IVECO MGP.

Moreover,

$LTne' = (L7' + L8' + L9') \times 12 = (44.88\ EUR + 53.43\ EUR + 61.98\ EUR) \times 12\ months = 1923.5\ EUR$ total annual fuel cost for handling all merged remote routes of northeastern Attica by the MGPs within the framework of the second improvement scenario.

Conclusively, the total annual fuel cost for the completion of all merged remote itineraries in western, eastern and northeastern Attica combined within the framework of the second improvement scenario is:

$LT' = LTw' + LTe' + LTne' = EUR\ 1918.8 + EUR\ 2604 + EUR\ 1923.5 = 6446.3\ EUR/year.$

CO_2 Emissions into the Atmosphere from the MGPs in the Second Improvement Scenario

As it has already been mentioned and confirmed by the EEA through a worldwide harmonized light-vehicle test procedure (WLTP, a testing procedure used to find out the real-world fuel economy and CO_2 emissions of a vehicle), an IVECO DAILY 35S18 MGP emits A1 = 309 g CO_2/km when it only carries its basic equipment, while it releases A2 = 425 g CO_2/km when it is filled with collected clean recyclable materials and A3 = 367 g CO_2/km when it is half-filled with collected clean recyclable materials (from the average of A1 and A2) [12]. Substantially, for the calculation of CO_2 emissions that are released from the MGPs into the atmosphere, the following calculations are made, taking into account all the aforementioned distances in western Attica, in eastern Attica and in northeastern Attica that have already been presented and consequently adopted. Therefore, in this second improvement scenario, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of western Attica merged remote itineraries:

$E1' = (Xwd/3 \times A1) \times 4 = (159.9/3\ km \times 309\ g\ CO_2/km) \times 4\ weeks = 65{,}878.8\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their decentralized local depot to their first remote municipal destinations in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

$E3' = (Xwd/3 \times A3) \times 4 = (159.9/3\ km \times 367\ g\ CO_2/km) \times 4\ weeks = 78{,}244.4\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their first remote municipal destinations to their second remote municipal destinations in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

A3: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is half-loaded (with collected recyclable materials).

$E2' = (Xwd/3 \times A2) \times 4 = (159.9/3\ km \times 425\ g\ CO_2/km) \times 4\ weeks = 90{,}610\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their return distances from their second remote municipal destinations back to their decentralized local depot in western Attica within the framework of the second improvement scenario, where

Xwd: Total distance of all MGP merged routes in western Attica within the framework of the second improvement scenario (Figure 7 and Table 2).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

$ETw' = (E1' + E3' + E2') \times 12 = (65{,}878.8\ g\ CO_2 + 78{,}244.4\ g\ CO_2 + 90{,}610\ g\ CO_2) \times 12\ months = 2{,}816{,}798.4\ g\ CO_2$ or 2817 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of western Attica merged remote routes within the framework of the second improvement scenario.

Furthermore, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of eastern Attica merged remote itineraries:

$E4' = (Xed/3 \times A1) \times 4 = (217/3\ km \times 309\ g\ CO_2/km) \times 4\ weeks = 89{,}404\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their decentralized local depot to their first remote municipal destinations in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

$E5' = (Xed/3 \times A3) \times 4 = (217/3\ km \times 367\ g\ CO_2/km) \times 4\ weeks = 106{,}185.3\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their first remote municipal destinations to their second remote municipal destinations in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

A3: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is half-loaded (with collected recyclable materials).

$E6' = (Xed/3 \times A2) \times 4 = (217/3\ km \times 425\ g\ CO_2/km) \times 4\ weeks = 122{,}966.7\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their return distances from their second remote municipal destinations back to their decentralized local depot in eastern Attica within the framework of the second improvement scenario, where

Xed: Total distance of all MGP merged routes in eastern Attica within the framework of the second improvement scenario (Figure 8 and Table 2).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

$ETe' = (E4' + E5' + E6') \times 12 = (89{,}404\ g\ CO_2 + 106{,}185.3\ g\ CO_2 + 122{,}966.7\ g\ CO_2) \times 12\ months = 3{,}822{,}672\ g\ CO_2$ or 3823 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of eastern-Attica merged remote routes within the framework of the second improvement scenario.

In addition, the following calculations are applied for the estimation of the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of northeastern Attica merged remote itineraries:

$E7' = (Xned/3 \times A1) \times 4 = (160.3/3\ km \times 309\ g\ CO_2/km) \times 4\ weeks = 66{,}043.6\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their decentralized local depot to their first remote municipal destinations in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

A1: Specific CO_2 emissions (WLTP) of an IVECO MGP when it only carries its basic equipment/net weight.

$E8' = (Xned/3 \times A3) \times 4 = (160.3/3\ km \times 367\ g\ CO_2/km) \times 4\ weeks = 78{,}440.1\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their transition distances from their first remote municipal destinations to their second remote municipal destinations in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

A3: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is half-loaded (with collected recyclable materials).

$E9' = (Xned/3 \times A2) \times 4 = (160.3/3\ km \times 425\ g\ CO_2/km) \times 4\ weeks = 90{,}836.7\ g\ CO_2$ total monthly emissions that are released by the MGPs into the atmosphere during their return distances from their second remote municipal destinations back to their decentralized local depot in northeastern Attica within the framework of the second improvement scenario, where

Xned: Total distance of all MGP merged routes in northeastern Attica within the framework of the second improvement scenario (Figure 9 and Table 2).

A2: Specific CO_2 emissions (WLTP) of an IVECO MGP when it is fully loaded (with collected recyclable materials).

Moreover,

ETne′ = (E7′ + E8′ + E9′) × 12 = (66,043.6 g CO_2 + 78,440.1 g CO_2 + 90,836.7 g CO_2) × 12 months = 2,823,844.8 g CO_2 or 2824 kg of CO_2 total annual emissions into the atmosphere from the MGPs during the completion of northeastern-Attica merged remote routes within the framework of the second improvement scenario.

Conclusively, the total annual CO_2 emissions into the atmosphere from the MGPs during the completion of all merged remote itineraries in western, eastern and northeastern Attica combined within the framework of the second improvement scenario are

ET′ = ETw′ + ETe′ + ETne′ = 2,816,798.4 g CO_2 + 3,822,672 g CO_2 + 2,823,844.8 g CO_2 = 9,463,315.2 g CO_2/year or 9463 kg of CO_2/year.

3. Results and Discussion

3.1. Comparison of THE GREEN CITY Recycling Program's Current Situation and Its Two Improvement Scenarios

The comparison between THE GREEN CITY recycling program's current situation and the first improvement scenario revealed interesting differences and results (Figure 10). First of all, the total annual distance of all remote itineraries in western, eastern and northeastern Attica is shortened from 70,531.2 km in the current situation to 40,377.6 km in the first improvement scenario (−30,153.6 km). Similarly, the total annual time that is needed for the completion of all remote itineraries is diminished from 69,312 min in the current situation to 48,288 min in the first improvement scenario (−21,024 min). Furthermore, the total annual fuel cost sum for the completion of all remote itineraries in western, eastern and northeastern Attica by the MGPs of "THE GREEN CITY" program is decreased from EUR 17,632.8 in the current situation to EUR 10,094.4 in the first improvement scenario (-EUR 7538.4), while the total annual CO_2 emissions into the atmosphere from the MGPs of "THE GREEN CITY" recycling program during the coverage of all remote routes in western, eastern and northeastern Attica are diminished from 25,885 kg of CO_2 in the current situation to 14,819 kg of CO_2 in the first improvement scenario (−11,066 kg of CO_2). So, in the first improvement scenario, the total annual distance sum of all remote itineraries in the three sub-areas of Attica, the total annual fuel cost for the completion of all these itineraries by the MGPs and the total annual CO_2 emissions into the atmosphere from the MGPs during the coverage of these remote routes are all reduced by 42.8% compared with the current total annual distance, the total annual fuel cost sum and the total annual CO_2 emissions of THE GREEN CITY recycling program, while the total annual time that is needed for the completion of all the aforementioned remote itineraries in this specific scenario is reduced by almost 30.3% compared with the current total annual time of THE GREEN CITY recycling program (Table 3).

Additionally, the comparison between THE GREEN CITY recycling program's current situation and the "second improvement scenario with main depot decentralization and the merge of neighboring remote routes"showed even greater differences and interesting results (Figure 10). Firstly, the total annual distance of all remote itineraries in western, eastern and northeastern Attica is shortened from 70,531.2 km in the current situation to 25,785.6 km in the second improvement scenario (−44,745.6 km). Similarly, the total annual time that is needed for the completion of all the remote itineraries is diminished from 69,312 min in the current situation to 32,256 min in the second improvement scenario (−37,056 min). Furthermore, the total annual fuel cost for the completion of all remote itineraries in western, eastern and northeastern Attica by the MGPs of "THE GREEN CITY" program is decreased from EUR 17,632.8 in the current situation to EUR 6446.3 in the second improvement scenario (-EUR 11,186.5), while the total annual CO_2 emissions into the atmosphere from the MGPs of "THE GREEN CITY" recycling program during the coverage of all remote routes in western, eastern and northeastern Attica are diminished from 25,885 kg of CO_2 in the current situation to 9463 kg of CO_2 in the second improvement scenario (−16,422 kg of CO_2). Therefore, in the second improvement scenario, the total annual distance of all merged remote itineraries in the three sub-areas of Attica, the total annual fuel cost for the completion of all the merged itineraries by the MGPs and the total annual CO_2 emissions into the atmosphere from the MGPs during the coverage of these merged remote routes are all reduced by 63.4% compared with the current total annual distance, the total annual fuel cost and the total annual CO_2 emissions of THE GREEN CITY recycling program, while the total annual time that is needed for the completion of all the aforementioned merged remote itineraries in this specific scenario is reduced by almost 53.5% compared with the current total annual time of THE GREEN CITY recycling program (Table 3).

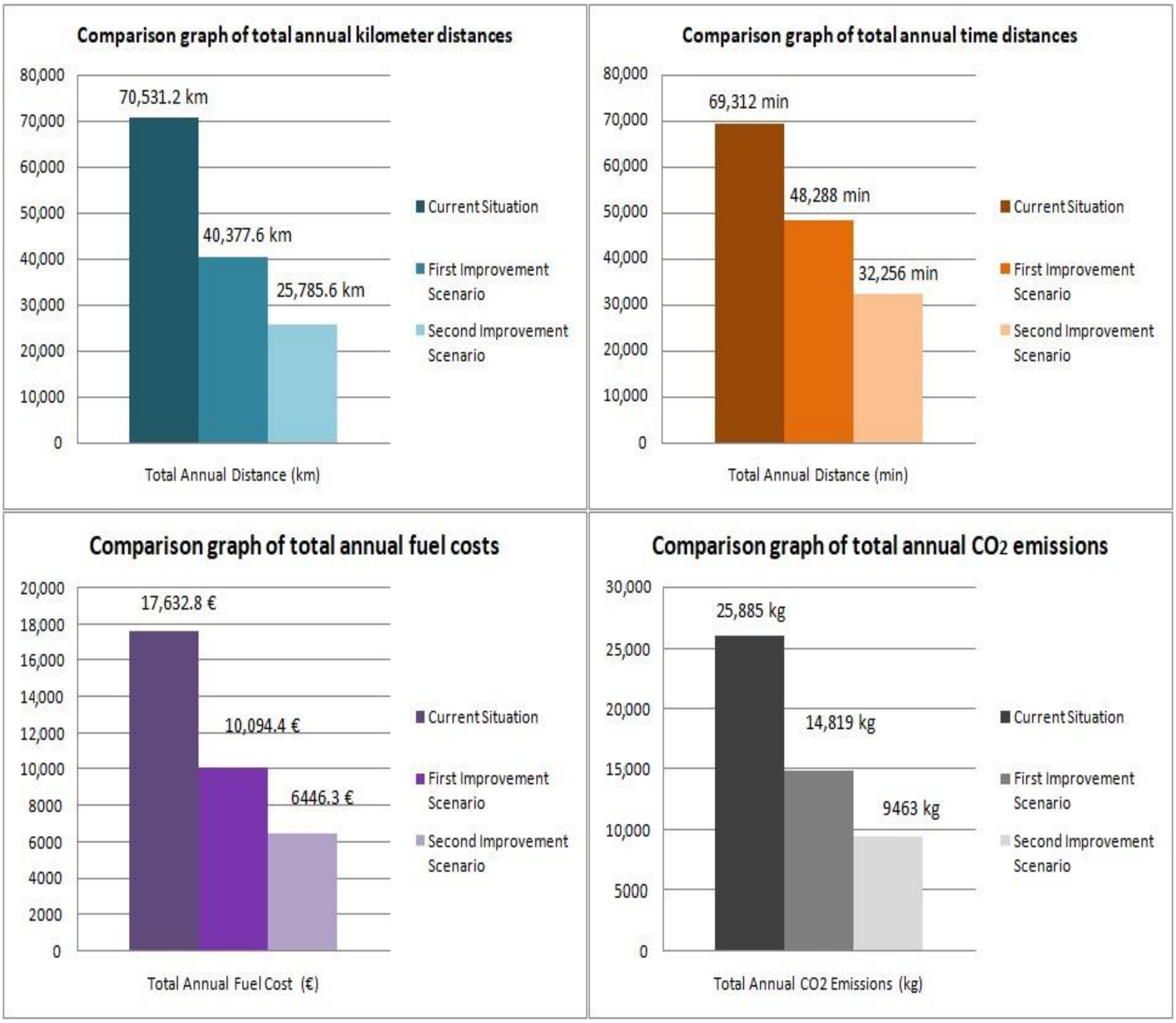

Figure 10. Distance, time, fuel costs and CO_2 emission graphs of "THE GREEN CITY" recycling program's remote routes in western, eastern and northeastern Attica (current situation, first improvement scenario and second improvement scenario). Source: Authors' own study.

Table 3. Distance, time, fuel costs and CO_2 emission differences between "THE GREEN CITY" recycling program's current situation and the first improvement scenario and between "THE GREEN CITY" recycling program's current situation and the second improvement scenario.

Comparison between Current Situation and First Improvement Scenario				
	Current Situation	**First Improvement Scenario**	**Difference**	**Percentage of Change**
Total Annual Distance (km)	70,531.2	40,377.6	−30,153.6	−42.8%
Total Annual Distance (min)	69,312	48,288	−21,024	−30.3%
Total Annual Fuel Cost (EUR)	17,632.8	10,094.4	−7538.4	−42.8%
Total Annual CO_2 Emissions (kg)	25,885	14,819	−11,066	−42.8%
Comparison Between Current Situation and Second Improvement Scenario				
	Current Situation	**Second Improvement Scenario**	**Difference**	**Percentage of Change**
Total Annual Distance (km)	70,531.2	25,785.6	−44,745.6	−63.4%
Total Annual Distance (min)	69,312	32,256	−37,056	−53.5%
Total Annual Fuel Cost (EUR)	17,632.8	6446.3	−11,186.5	−63.4%
Total Annual CO2 Emissions (kg)	25,885	9463	−16,422	−63.4%

3.2. Advantages and Disadvantages of THE GREEN CITY Recycling Program's First Improvement Scenario Compared with Its Current Situation

THE GREEN CITY recycling program's first improvement scenario presents significant advantages and disadvantages compared with the program's current situation (Table 4).

Table 4. Advantages and disadvantages of "THE GREEN CITY" recycling program's first improvement scenario compared with its current situation.

First Improvement Scenario Compared with Current Situation	
Advantages (+)	**Disadvantages (−)**
Distance reduction	Demand of significant capital expenditures for establishing decentralized depots
Route duration reduction	Lower accessibility to public transport for the employees of THE GREEN CITY program
Fuel-cost decrease	Increase in daily commuting costs for the employees
CO2 emission decrease	Indirect growth of THE GREEN CITY recycling program's carbon footprint due to lack of accessibility to public transport
Increase in MGPs operational lifetime	
Decrease in MGPs maintenance costs	
Strain decrease in MGP drivers and improvement in their health	
Air-pollution diminution in Attica region	
Mitigation of climate change's negative impacts	
Increased energy conservation	
Recycling program's operational-cost reduction	

On the one hand, kilometer and time reductions of all remote itineraries in western, eastern and northeastern Attica are important advantages as long as they reduce the maintenance costs of all MGPs and remarkably increase their operational lifetime. Furthermore, these kilometer and time reductions decrease the MGPs' drivers strain and improve their physical and mental health. Additionally, the decrease in the total annual fuel costs for the MGPs, in order to complete all their remote itineraries in the prefecture of Attica, is another advantage of this first improvement scenario as long as it contributes to energy conservation (fuel conservation) and it cuts the recycling program's operational costs (fuel costs) without doubt. Finally, the reduction in CO_2 emissions into the atmosphere from the MGPs during the completion of all remote itineraries in this specific improvement scenario is an important environmental advantage that considerably diminishes air-pollution rates in the Attica region and generally mitigates many of the negative impacts of climate change, compared with the program's current situation.

On the other hand, this first improvement scenario demands significant capital expenditures by THE GREEN CITY recycling program's operators for renting or buying new lands that will suitably host the three new decentralized depots of the MGPs. Subsequently, the proposed decentralization of the main depot of the MGPs at Tavrou 50 (Athens metropolitan Area) to three different depots in the three sub-areas of western, eastern and northeastern Attica will lower the accessibility of THE GREEN CITY program's employees to public transportation methods, which are mainly concentrated in Athens, and it will increase their daily commuting costs. Lastly, this lack of accessibility due to the remote new locations of the three decentralized depots in the three sub-areas of Attica will indirectly grow THE GREEN CITY recycling program's carbon footprint.

3.3. Advantages and Disadvantages of THE GREEN CITY Recycling Program's Second Improvement Scenario Compared with Its Current Situation

Similarly, THE GREEN CITY recycling program's "second improvement scenario with main depot decentralization and the merge of neighboring remote routes" presents substantial advantages and disadvantages compared with the program's current situation (Table 5).

Table 5. Advantages and disadvantages of "THE GREEN CITY" recycling program's second improvement scenario compared with its current situation.

Second Improvement Scenario Compared with Current Situation	
Advantages (+)	**Disadvantages (−)**
Great distance reduction (monthly and annually)	Significant capital expenditure demand for establishing decentralized depots
Significant time reduction (monthly and annually)	Lower accessibility to public transport for the employees of THE GREEN CITY program
Great fuel-cost decrease	Increase in daily commuting costs for the employees
Great CO_2-emission decrease	Indirect growth of THE GREEN CITY recycling program's carbon footprint due to lack of accessibility to public transport
Increase in MGPs' operational lifetime	Increase in distance (daily)
Decrease in MGPs' maintenance costs	Increase in time (daily)
MGP drivers' strain decreases and improvement in their health (long term)	Increase in MGP drivers' strain and deterioration of their health (short term)
Air pollution diminution in Attica region	High implementation uncertainty
Mitigation of negative impacts of climate change	
Increased energy conservation	
Recycling program's operational cost reduction	

* Great kilometer distance reduction is also consistent with the outcomes of Table 3, referring to the fact that trips have been merged and because of this the trip distances increased but the total distance travelled across the system is reduced.

On the one hand, the second improvement scenario has almost the same advantages with the "first improvement scenario with main depot decentralization" but to a greater extent. This is because the distance and time shortenings, fuel-cost cuts and CO_2-emission reductions are greater within the framework of this specific scenario than those of the first scenario. In addition, this second improvement scenario has all the aforementioned disadvantages of the first improvement scenario accompanied by some additional ones. For example, all these merged remote itineraries within the framework of this scenario have decreased weekly or annual kilometer and time distances for the MGPs in the three sub-areas of the Attica prefecture but they also show increased daily kilometer and time distances. This reality reveals a reduction in the MGP drivers' strain and an improvement in their physical and mental health in the long term; however, it demonstrates at the same time the growth of their strain and the deterioration of their physical and mental health in the short term. Finally, the high implementation uncertainty of this second scenario compared with the first improvement scenario and THE GREEN CITY recycling program's current situation is another major disadvantage as long as it is ideally planed and calculated. For instance, the total distances of all merged remote routes in western, eastern and northeastern Attica are perfectly and equally divided into three parts: the first part where the MGPs begin their daily merged remote routes from their decentralized depot to their first municipal destination, the second part where the MGPs travel from their first daily municipal destination to their second municipal destination, and the third part where the MGPs complete their daily merged remote routes and eventually return back to their decentralized local depot. In addition, all the MGPs loaded with collected recyclable materials are optimally allocated in these three parts. Specifically, during the coverage of the first part, the MPGs travel unloaded, during the coverage of the second part, the MPGs travel half-loaded with collected recyclable materials, and lastly during the coverage of the third part, the MPGs travel fully loaded with collected recyclable materials. So, these two aforementioned main assumptions are probably overoptimistic and indicate that this second improvement scenario is far from becoming a reality.

3.4. Managerial Constraints, Research Challenges and Future Considerations

Today, the structure of MSW collection is indeed a more challenging issue than ever before, due to the vast variations and diversification of today's consumer behaviors and habits compared to the past 3–4 decades and earlier. For instance, the wider commercialization of personal computers and their utilities make electronic waste among the most notable sources of environmental hazards, but it also contains valuable raw materials that can be recycled or repaired. In this context, new plans and designs for the collection of such types of waste, as well as for the reverse logistics, are essential to minimizing their inappropriate disposal. The case of waste collection is not solely environmental, since multi-electronic products, multi-manufacturers and multi-retailers are interested in this topic. Therefore, for end-of-life products, reverse-logistics network can collect the e-waste in return processors where testing, sorting, and disassembling can be carried out and then sent to repair and recycling units. In addition, components that cannot be repaired or recycled can be shipped to a secondary manufacturer as raw materials. In this way, the development of an electronic product's reverse-supply chain is expanded to envisage the idea of e-waste nullification and the adoption of suitable strategies that could support managers in ensuring long-term sustainability [15].

Regarding the idea of vast nullification in the relevant literature, two parallel production and consumption supply chains were also proposed [16]. In this study the circular economic core concept of 3R (reduce, restore, and recycle) was incorporated into this study. This process contained successive production chains of the thoughtful shipment of waste to the recycling industry, as well as waste losses due to damage or leakage from the waste containers. The overall process can be validated by the optimal values of the price discount and container-leakage cost, emphasizing the principles of a circular economy [17,18]: reducing and restoring waste in successive steps [16]. The high sensitivity of the restoration of waste for recycling can optimize the entire cost of the supply chain, while a primary chain can further reduce the generation of waste as a result of the price-discount policy [16].

At this point, it is also important to note the energy concerns and considerations that are today even more striking and demanding. In this context, biofuels are viewed as viable alternatives to non-renewable energy sources for energy generation, even those produced by animal fat, waste cooking oil, and vegetable oil, that are cheap and convenient raw materials that can be utilized to make biodiesel. In the relevant literature a mathematical optimization model was proposed to plan a sustainable supply chain for biodiesel made from waste animal fat, aiming to lower the biodiesel supply-chain cost and its environmental impact while also maximizing its social impact. The roles of social media promotion and advertising, together with governmental subsidies of collecting waste animal fat, can demonstrate that the transportation cost is 51.34% and the installation cost of biodiesel production facilities accounts for 21.26% of the total cost, while the environmental installation impact of biodiesel production facilities accounts for 99.94% of the total environmental impact and the employment of a heterogeneous fleet of trucks to supply materials for the supply chain can contribute to 0.0005% of the total environmental impacts. The social impact also regards the life-cycle assessment which is 1.363% for this model, thus, supporting policymakers and investors to be actively engaged in the biodiesel industry [19]. At the following subsections the main environmental, economic–financial and humanitarian–anthropocentric dimensions of the proposed MGPs' scenarios are presented.

3.4.1. Environmental Dimension

The Attica region is regarded as one of the most arid urban regions in Europe. In this context, it is noteworthy that its climate regime has been influenced by the intense urbanism of the four recent decades, showing moderate warming, wind speed and direction changes and multiple extreme events. In addition, the multi-component industrial rise since 1960 is characterized by a declining trend to date; however, it has determined drastic changes in the use of land, which has led to both environmental degradation and impacts on the local climate regime, expanding into the adjacent suburban areas. Moreover, industrial activity is manifested by high contents of metals and oil products [20]. In the relevant literature, studies have focused on the pollution record of selected points, sampling stations, of Attica, indicating the temporal evolution of legislated polluting compounds and thus, supporting researchers in providing solutions and forcing policy-makers to focus on potential policy alternatives for the whole Attica region of [20].

In a recently published study on the western Attica region and an industrial zone in the neighborhood Thriasio, it was argued that sulfur dioxide (SO_2) concentrations had gradually decreased over the years thanks to fuel improvement, whereas nitrogen dioxide (NO_2) concentrations had remained almost the same, or that there had been perhaps a small decreasing trend during the last few years. Yet, the levels recorded at the nearby industrial zone of Attica were less than those observed in the Athens center: this indicates that the sea breeze is, potentially, either beneficial as effective ventilation, or detrimental through the transportation of polluting elements. Moreover, elemental concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^+, NH^{4+}, Cl^-, $NO_3{}^-$ and $SO_4{}^{2-}$ were determined in airborne particulates and were attributed to industrial activity. Specifically, ammonium is likely to originate from the oil refineries and is enriched in the fine particles, chloride is due to a coastal effect and nitrate concentration is due to vehicle emissions. In the Attica urban/center area, the enrichment of secondary aerosols, ammonium, and sulphates, in the fine particle fraction can reflect high traffic densities and domestic heating from the highly populated cities. Similarly, only Al, Ba and Zn were abundant while Cr, V, Mn, Pb, Cu, Ni, Ga and Rb were detected in traces. For PM_{10}, Al, Fe, Zn and Ba demonstrated the maximum concentrations during winter. Makri et al. [20] also concluded that the industrial area was the main polluting source, specifically for Cd, whereas Pb originated from combustion processes due to municipal solid waste incineration, confirming our proposal of waste selection at the source as an imperative necessity. Ultimately, air pollution can strongly impact residents' health, as an assessment of the lifetime cancer risk revealed that two people out of 30,000 are at risk [20].

Regarding the photochemical air pollution, an early study (published two decades ago) identified that the levels of photochemical air pollutants O_3, NO, and NO_2 could be monitored in Athens and in the neighboring (northeastern to Athens' center) region of the Mesogia plain (Spata, Artemis and Markopoulo) [21]. The phytodetection of ozone was conducted using bioindicator plants and tobacco varieties, revealing that the average maximum daily O_3 concentration was 60–75 ppb, while the 24 h average ranged from 40 to 65 ppb. It is also noteworthy that both ozone bioindicator plants and tobacco varieties were highly injured in all regions, confirming the phytotoxicity of those ozone levels. The levels of recorded NO and NO_2 at the three experimental stations in the Mesogia plain were considerably lower than those occurring in Athens' center, enabling the disclosure of important background information concerning pollution levels in the Attica Region and its suburban areas, mainly those areas of the Mesogia plain that had accommodated the new international airport "Eleftherios Venizelos" in the region since March 2001 [21].

3.4.2. Economics–Financial Dimension

The inverse relationship between the "MGPs maintenance costs decrease" and the "number of routes"/"distance of route" was also anticipated, since as fewer and shorter routes are made by the collection trucks, there are lower operational and maintenance costs of the whole truck fleet. Our research proposal for the future of waste-collection methods is highly linked to the transition to electric vehicles (EV) (truck in our study), having a positive sustainable impact on the climate, the environment, and society [22]. Indeed, from an environmental perspective, the comparison of GHG emissions in EVs to vehicles/trucks with internal combustion engines showed that for 60% of households in the US, there are moderate to high savings to be made (i.e., 2.3 metric tons of CO_2 reduction per household annually; 0.6% of energy-burden reduction). In terms of economics and energy regarding fuel costs and the transportation energy burden (i.e., percentage of income spent on vehicle fuels), excluding the purchase cost of the vehicles themselves, it was reported that over 90% of vehicle-owning US households would see reductions in both GHGs and transportation energy burden by adopting an EV [22].

These reductions are especially pronounced when combining them with cleaner electricity grids, lower electricity prices (relative to gas prices), and smaller drive-cycle and temperature-related impacts on fuel efficiency. Moreover, adopting an EV would more than double the percentage of households that could enjoy a low transportation-energy burden (2% of income spent on fuel annually). This equates to 80% of all vehicle-owning U.S. households. Nevertheless, over half of the lowest-income households would still have a high EV energy burden (4% income spent on fuel annually and due to no access to at-home charging this would rise to over 75%). In a wider environmental and energy-planning context, while addressing the aforesaid inequity, the following interventions are recommended: (a) targeted policies to promote energy justice in lower-income communities, including subsidizing charging infrastructure; (b) strategies to reduce electricity costs; and (c) expanding access to low-carbon transport infrastructure (e.g., public transit, biking, and car sharing) [22].

3.4.3. Humanitarian–Anthropocentric Dimension

Stress is the primary cause of strain and health problems for occupational drivers whose jobs directly relate to public safety. Although several stress theories and scales have been proposed, the exact method of adequately measuring the stress of occupational drivers remains unclear [23]. The driver strain in our study is a subjective feeling that is primarily determined by the drivers' professional experience in driving with a full cargo, the driving safety in alignment with the number of routes driven, and their total time on the go. In the relevant literature, research has focused on the reliability and validity of the associated strain and health problems of occupational drivers. Indicative parameters were those of burnout levels, cardiovascular disease symptoms, and self-rated health. In addition, physical demands, overtime, and stress-induced sleep problems were the primary stressors in occupational drivers [23]. It was shown that an imbalance between effort and reward and overcommitment levels were strong and independent predictors of strain and health outcomes. Future studies should be also directed to develop a reliable tool to identify and to measure the stress of MGP professionals, similar to those working as public transport drivers, under strain conditions and the health levels of suspected unhealthy drivers [23].

In the relevant literature, a considerable divergence in organization and management practices that are associated with the performance of mental health providers was highlighted; thus, there is an imperative need to compare and contrast the core organizational processes across high- and low-performing mental-health providers and national health service centers. To this end, a research design can incorporate a full sample of low- and high-performing mental-health service providers, suggesting that the organizational approaches used to govern and manage mental-health service providers are associated with their performance. The research outcomes enabled a better understanding of what areas might need attention, including the development of appropriate governance frameworks and organizational cultures, in order to ensure that staff across the organization (in our study, the MGP waste-collection management) feel "psychologically safe" and able to speak up when they see things that are going wrong. In addition, focus should be directed on enhancing the quality of services rather than prioritizing cost reduction; investing in new technology and digital applications; and nurturing positive inter-organizational relationships across the local health economy [24]. Last but not least, to evaluate the inadequacies faced by the public in accessing mental-health services and the directions to improve in the future, it is crucial to provide socially inclusive services to drivers, enabling them to live a life free from mental-health-related stigma or discrimination [25].

4. Conclusions

The two improvement scenarios estimations of "THE GREEN CITY" recycling program revealed that practical and realistic solutions can significantly improve a program's or a project's viability, tolerability, and equitability. Decentralization and the consideration of each region's geographical features are two important factors that can improve waste-management systems and especially waste-collection recycling programs. For instance, these two factors can shorten their collection routes and improve their collection service time for both citizens and businesses. Furthermore, they can enhance fuel cost efficiency, energy conservation and carbon footprints of all waste-collection recycling programs. Lastly, the careful decentralization of the main facilities and thorough study of each region's geographical features can considerably increase the operational lifetime of the mechanical equipment of each waste-collection recycling program and reduce strain, and at the same time reduce stressful conditions for their employees, notably for the drivers of their mobile waste-collection equipment or their specially formed recycling vehicles. Therefore, many of the aforementioned practical and realistic solutions, which are included in each of the two "THE GREEN CITY" recycling program's improvement scenarios, can generally guarantee a recycling program's long-term sustainable implementation and operation by equally respecting all three sustainability pillars (financial, social and environmental).

However, improvement changes and scenarios are accompanied by disadvantages too. Substantially, the administrators or the operators of a waste-management system like a waste-collection recycling program should take into account all new arising parameters and every one of their positive or negative impacts. Then, the total sum of impacts can affect the final implementation decision of an improvement scenario. If this sum is positive that means that the positive impacts exceed the negative ones. On the contrary, if this sum is negative that means that the negative impacts exceed the positive ones. Furthermore, the magnitude of positive or negative total sums of each scenario must be taken into account and compared in order to help in rational decision making. For example, both of the improvement scenarios for THE GREEN CITY" recycling program actually have positive total sums of impacts but the "first improvement scenario with main depot decentralization" has, indeed, a bigger positive total sum than the "second improvement scenario with main depot decentralization and the merge of neighboring remote routes", which is why this paper introduces the first improvement scenario as a more realistic and feasible scenario and strongly suggests its implementation.

So, waste-management systems and recycling programs should make improvement changes during their operational duration, which will be practical, realistic and easily adapted to each region's special socioeconomic, environmental, geographical and spatial realities. As stagnation can severely harm viability, tolerability and equitability, every implemented improvement change for waste-management systems and recycling programs has to follow the main principals of sustainability and serve, to the maximum possible extent, the national, regional or local economic, social and environmental needs.

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