sustainability

MDPI

Article

A Multi-Objective Model to Find the Sustainable Location for Citrus Hub

Emad Alzubi * and Bernd Noche

Transportsysteme und-logistik, Fakultätsingenieurswissenschaften, Universität Duisburg—Essen, Keetmanstr. 3-9, 47058 Duisburg, Germany
* Correspondence: emad.alzubi@stud.uni-due.de

Abstract: Citrus supply chains (CSC) are increasingly important in research due to high loss and waste, increasing demand, wide application for other industries, and differences in CSCs from country to country. This study proposes a new structure for CSC by introducing collection points to collect citrus from the farms in Jordan Valley and transport it to a citrus hub responsible for receiving, packaging, and transporting the citrus to distribution centers. The objective of this structure is to minimize the loss and waste and provide a new supply chain (SC) with stable infrastructure to track citrus from the initial stages and implement technologies such as the Cold SC. Therefore, it is crucial to find the optimum number of collection points, citrus hubs, and locations based on carbon footprint and transportation costs. The model introduced was solved using Open Solver Adds-ins after collecting data such as distances and coordinates using Google Maps and the altitude of those coordinates from SolarGIS. After running the model, it was found that the optimum number of collection points is 52 and the optimum number of citrus hubs is two. The results showed that the transportation costs of one hub are lower by 30%, whereas for two hubs are lower by 60% compared to the current location of the central market of fruits and vegetables (CM). The "kg CO_2 e/kg citrus" values are 0.48 and 0.24 for one hub and two hubs, respectively, which showed a significant reduction compared to CM, which was 0.69 kg CO_2 e/kg citrus. Therefore, installing two citrus hubs will improve the overall sustainable performance of CSC. Future research might be directed to integrate the circular economy into CSC and find possible applications for citrus loss and waste.

Keywords: citrus; facility location; transportation costs; CO_2 emissions; center of gravity; sustainability

check for updates

Citation: Alzubi, E.; Noche, B. A Multi-Objective Model to Find the Sustainable Location for Citrus Hub. *Sustainability* **2022**, *14*, 14463. https://doi.org/10.3390/su142114463

Academic Editors: Elżbieta Macioszek, Anna Granà, Raffaele Mauro and Margarida Coelho

Received: 30 September 2022
Accepted: 2 November 2022
Published: 3 November 2022

1. Introduction

Determining a facility's location, which has several applications for logistics operations, is vital in optimizing supply chains (SC). The facility location problems have attracted researchers for a long time. For instance, Miehle [1] proposed a model to minimize the distance between fixed centers' locations. Still, the interest in employing similar approaches and algorithms appeals to recent research in different applications. For example, Labbe' et al. [2] introduced bilevel models for controversial facilities. Brandstätter et al. [3] employed a similar approach to identify charging stations' locations for electric vehicles, whereas Ahmad et al. [4] utilized the central of gravity (CoG) for the same purpose. Lin et al. [5] used a such algorithm to find the optimum locker location for the last-mile delivery. It has also been used in humanitarian logistics for determining the location of refugee accommodations [6]. In addition, Nalan Bilişik and Baraçlı [7] found the optimum location for a fruits and vegetables (FV) market hall using a fuzzy goal programming model. Although CoG can be used to determine a facility location, as Altay et al. [8] did, it considers only the objective of minimizing the distance and transportation costs [9].

Finding the optimum location of a facility has been widely studied as well. For instance, Cooper [10] employed the facility location algorithm and built a model to determine the optimum warehouse location and allocate customer demands. The attention to the facility location algorithm is getting increasing importance in research. It has been used in research for several purposes, such as dynamic period location [11,12], continuous site location [13], a joint facility location-allocation [14], multi-facility locations [15], and multi-objective facility location [16–18]. The multi-objective facility location problem was employed by Harris et al. [17] to determine the optimum facility location while considering the minimum cost and CO_2 emissions. In addition, several extensive literature reviews on facility location problems have been done, for example, Jolai et al. [19], Al-Haidary et al. [20], Klose and Drexl [21], and Melo et al. [22].

However, the studies noted considered the minimum cost in determining the optimum location, but other factors might be included when identifying a facility location. For instance, Wolff et al. [23] considered the amount of CO_2 emission crucial when solving such problems. Xifeng et al. [24] developed a multi-objective model that minimizes transportation costs and carbon footprint to improve sustainability because transportation significantly contributes to the global carbon footprint [25]. Factors influencing transportation CO_2 emission include the type and number of vehicles, fuel type, infrastructure, road quality, slope, and many others [26]. The methodology developed by the Network for Transport and Environment (NTM) depends on several factors related to diesel consumption, distance travelled, and load [25].

Finding an optimum facility location in food SC (FSC) significantly reduces food loss and waste (FLW), which is getting increasingly important to researchers, SC practitioners, and decision-makers from all around the globe due to its direct relation to sustainability. Thus, reducing FLW leads to improving sustainable performance [26], as it directly relates to enhancing competitiveness, for which Alzubi and Akkerman [27] concluded that it has a steady relationship to sustainable performance. However, managing FSC requires more attention from all parties within it due to the sensitive products that it deals with, especially FV.

However, 45–55% of FV produced worldwide are considered FLW [28], which makes FSC difficult to manage. Nevertheless, FLW causes vary from stage to stage within FSC. For instance, Surucu-Balci and Tuna [29] investigated drivers to FLW within the logistics operations and reported the following causes: delays, transportation costs, lack of technology in transportation and storage, poor transportation infrastructure, and transparency-related factors such as information sharing. Other researchers also reported that delays within the SC are a significant cause [30–32]. In addition, transportation cost is another driver recorded by Chauhan et al. [33]. Other factors, such as the lack of technologies, would increase FLW in logistics and storage operations [32,34,35]. Moreover, the lack of logistics infrastructure, poor materials handling, poor packaging operations, and lack of communication and coordination between SC stakeholders [36] play a part. Gogo et al. [32] identified causes in the market that increase FLW: poor handling, poor packaging, market hygiene, lack of cold storage facilities, and lack of buyers. Nicastro and Carillo [37] discussed damage to the packaging materials, as they accelerate and contribute to spoilage.

Higgins and Ferguson [38] defined the freight village as a location where all logistics operations are performed to meet the domestic and offshore markets' demand. These operations include transportation, warehousing, packaging, distribution, and other related logistics. A specialized logistics hub for fruits or vegetables can improve the performance of its SCs. Fruits hub (FH) was defined, in addition to the definition of freight village by Higgins and Ferguson [38], and extended to include the related logistics activities, required technologies and equipment for FV, and the reverse logistics operations, that might be responsible for collecting packaging boxes and FLW from the downstream SC stages [39].

The SCs of citrus products differ from country to country, which attracted researchers such as Cheraghalipour et al. [40], Roghanian and Cheraghalipour [41], and Alzubi and Noche [42]. The flow of citrus products mainly starts from farms to processors, wholesalers, and retailers, and finally to the consumers, with many logistics operations and intermediaries in between, as illustrated in Figure 1. Moreover, Hasan et al. [43] stated that citrus production is increasing worldwide, leading to an increase in total citrus loss, according to Ademosun [44], which was estimated at 20% annually by the Food and Agriculture Organization (FAO) [45]. However, this paper contributes by defining a modern CSC that will enable the minimization of transport costs, CO_2 emissions, and the level of citrus losses and waste.

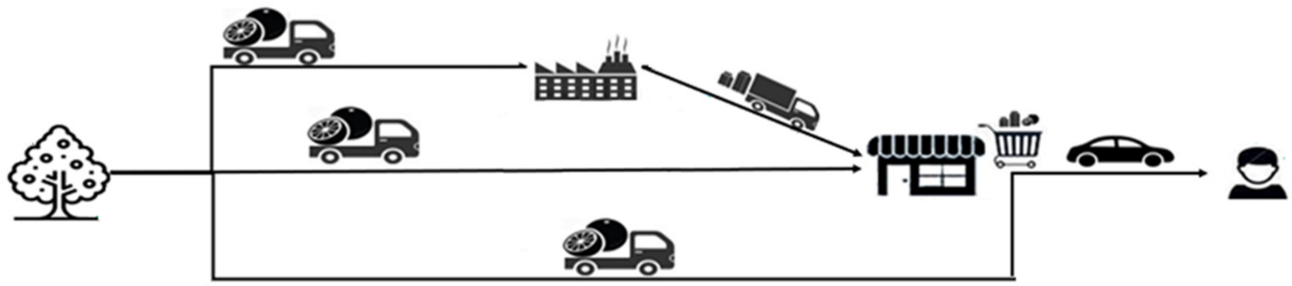

Figure 1. Citrus supply chain (created by the authors).

Problem Definition

In Jordan, the area planted with citrus is 5773 ha, where 89% of the planted area is in Jordan Valley (JV) and divided into 1977 agricultural units, each of which is 3–4 ha [46]. Citrus produced in JV includes orange, grapefruit, lemon, lime, pomelo, mandarin, clementine, tangerine, and kumquat [42]. Currently, each farmer is responsible for transporting their citrus from the farm in JV to the central market of fruits and vegetables (CM), with distances varying from 40 km to 170 km. In addition, each retailer uses a private truck to transport their merchandise from CM to their stores, leading to a vast number of vehicles used daily for transporting citrus around the country.

Citrus loss on the farm was estimated at 20% [42], generated due to factors such as the number of workers hired and infestation by insects. In addition, Alzubi et al. [47] found that transportation to CM contributes 11–16% and around 13% from CM to the retailer. In total, citrus loss constitutes at least 43% of citrus produced in Jordan.

This study proposes a modern design for citrus SC (CSC) in Jordan, intending to reduce CLW and carbon footprint during transportation. However, the study is the first to propose a solution for reducing CLW with a high potential to reduce CO_2 emissions by transporting the citrus through the SC. It also estimated the current CO_2 emissions from transporting citrus in Jordan. The proposed CSC is illustrated in Figure 2 by inserting a new stage into the CSC in Jordan, the citrus hub (CH). The CH is responsible for managing CSC stakeholders to enhance the overall sustainability performance. It can help to promote the CSC by integrating reverse logistics and applying other technologies, such as the Internet of Things (IoT), block chain (BC), cold SC, and many others, within the SC, as shown in Figure 2. It can also provide a stable infrastructure for integrating the circular economy with the SC.

Therefore, this paper aims to find the requirements of the proposed CSC to enhance its sustainable performance in Jordan. In addition, the study employed the facility location algorithm, CoG, and resource allocation to identify the required number of nodes and their locations. The remainder of the paper is divided as follows: Section 2 discusses the employed materials and methods, data collection, the mathematical model, and location evaluation criteria. In Section 3, the results from the model are presented, evaluated, and discussed. Finally, conclusions, implications, and future research directions are discussed in Section 4.

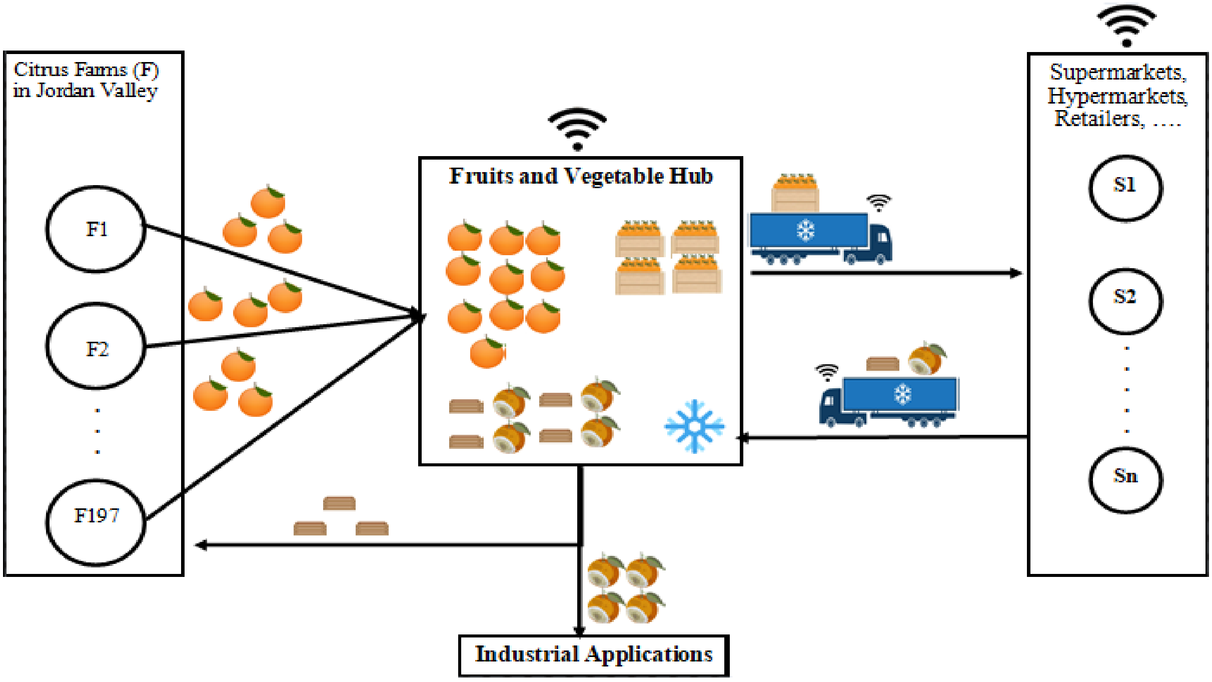

Figure 2. Proposed citrus hub with responsibilities.

2. Materials and Methods

The modern design of CSC has several goals: reducing the CLW, minimizing the transportation costs, cutting the CO_2 emissions during transportation, and providing an infrastructure to apply other concepts and technologies such as block chain (BC), Internet of Things (IoT), circular economy (CE), and closed-loop SC (CLSC). Therefore, the modern design will include two new nodes: collection points (CP) to collect the citrus from farms, and CH to collect citrus from CP, process it, and distribute it to 12 distribution centers (DC), each located in one of the governorates.

Because the CPs and the CH will be inserted into the CSC, the optimal location and requirements must be considered when redesigning the CSC. However, we focus on the case of the citrus farms in JV, illustrated in Figure 3, which represent the geographic location of JV. To reach the aim of the study, the analysis was performed for each stage separately. For instance, we first determined the number of required CPs, locations, and capacities (Section 2.1). In the second stage, we determined in Section 2.2 the required number of CHs and locations according to several steps, which are: (i) using CoG to determine the location based on the demand and supplies (Section 2.2.1), (ii) analyzing 13 different locations, in addition to the location determined by CoG, in terms of diesel consumption and CO_2 emissions (Section 2.2.2), (iii) and finally, comparing the locations with the current location of CM to identify the costs and CO_2 cut when implementing the modern structure. In the third stage, all CPs and distribution centers (DC) were assigned to at most one CH.

2.1. Determining the Required Number of CPs and Their Locations

The objective of inserting the CPs is to minimize the time from cultivation to arrival at the citrus hub while simultaneously maintaining total costs at a low level. Therefore, the capacity of each CP should be limited and specified. Additionally, it should be very close to the assigned farms so that the farmer is responsible for cultivating the citrus, collecting it in boxes, and getting it ready to be transported by a routing vehicle to the assigned CP. Figure 4 presents the CP and allocated farms, where the closed point represents the CP, and the open circles represent the assigned farms to this point.

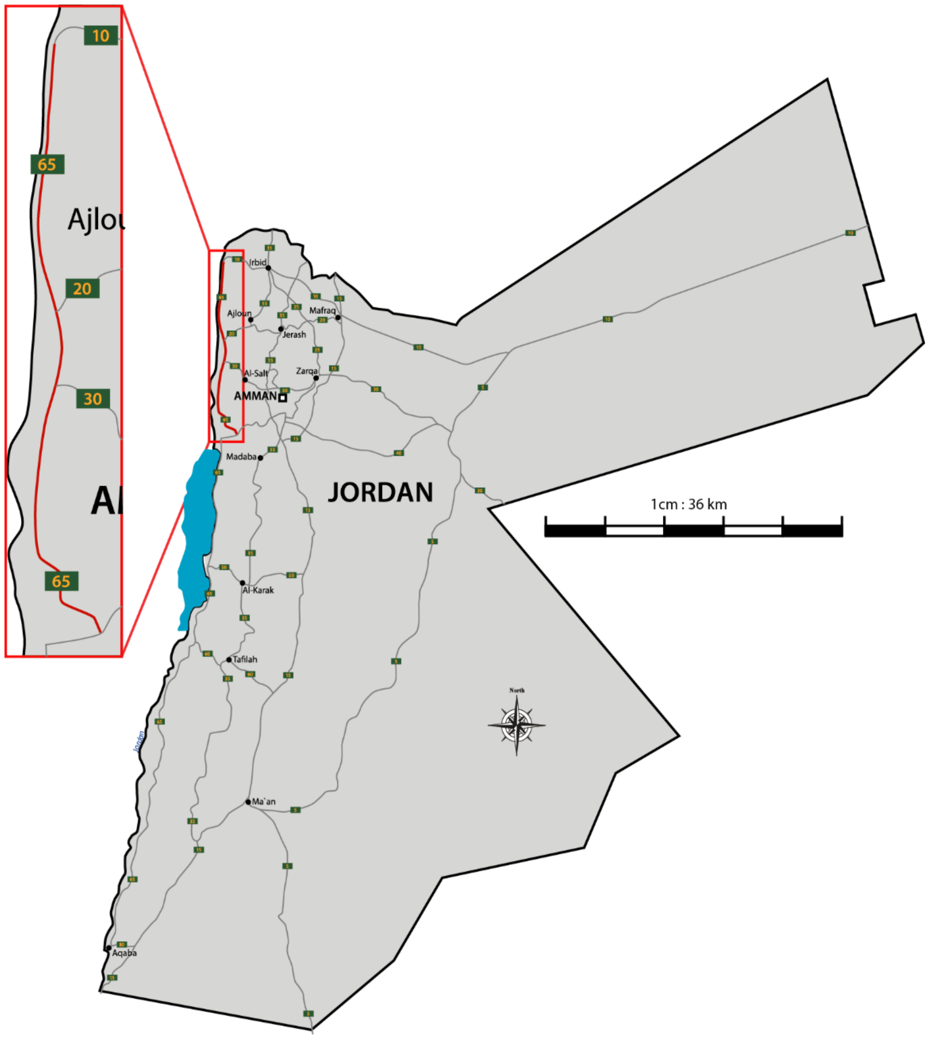

Figure 3. Location map of JV in Jordan (drawn by authors).

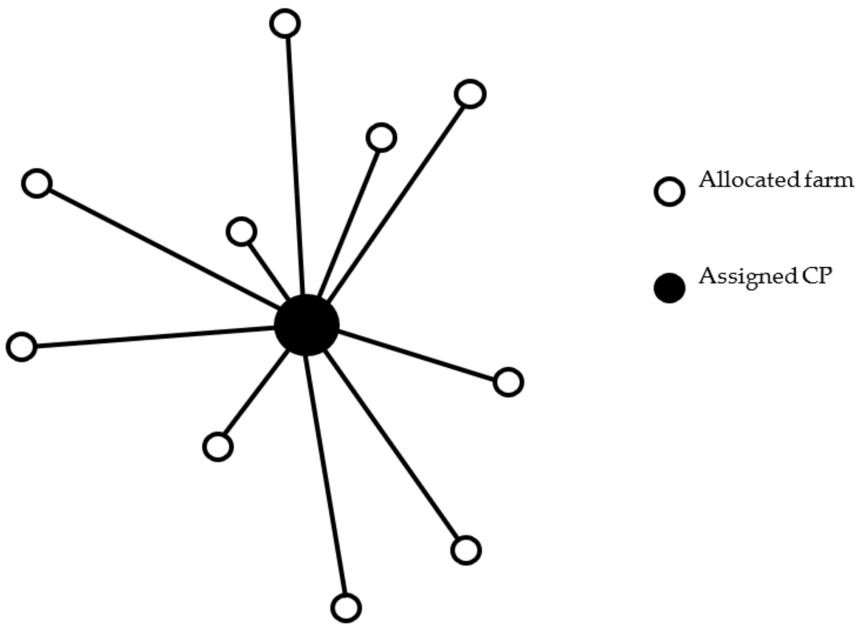

Figure 4. CP and the allocated farms.

However, each farm in JV is connected to at least one small road connected to JV's main street (Figure 5). The length of the main street of JV is 102 km, with several exits to other main streets. Therefore, all CPs should be located close to the main street of JV. At this stage, we marked the most northern point (colored in red) as a reference point with a distance of 0 km and initially proposed a CP every 1 km, with a total of 102 CPs. An assumption has been made: the maximum capacity of each CP is set at 30 euro-pallets (each of 6 layers of 4 boxes, which has a capacity of 20 kg) to minimize the time from cultivation to reach the hub. All collected citrus at each CP will be sent to the citrus hub. The following mathematical model was built based on the specified constraints to minimize the distance traveled from farms to the CPs.

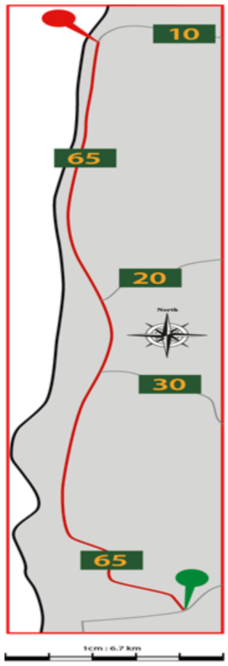

Figure 5. Main street of JV with a total length of 102 km.

Notation:

x: *Decision variable*, decides on assigning farms to a specific collection point;

d_c: *Distance between a collection point and the starting point;*

d_{fc}: *Distance between a farm and the allocated collection point;*

c: Collection point, which is allocated for a specific farm (f);

f: farm, which is assigned to a specific collection point;

a: altitude, which is the elevation of a specific location.

Objective function: Minimize distance traveled from farms to CPs

$$minimize\ D = \sum_{f=1}^{F} \sum_{c=1}^{C} d_{fc}.x_{fc}$$

Constraints:

$$x_{fc} = \begin{cases} 1, \ when\ farm\ (f)\ is\ assigned\ to\ collection\ point\ (c) \\ 0, \ elsewhere \end{cases} \quad (1)$$

$$\sum_{c=1}^{C} x_{fc} = 1, \ for\ each\ f \tag{2}$$

$$\sum_{f=1}^{F} x_{fc} \leq 10, \ for\ each\ c \tag{3}$$

$$d_c - d_{c-1} \geq 1, \ for\ each\ c \tag{4}$$

$$\sum_{c=1}^{c} d_c - d_{c-1} = 102, \ for\ all\ c \tag{5}$$

Assumptions:

$$a_c = -200\ m, \ for\ all\ c \tag{6}$$

Constraint (1) decides upon matching farms (f) to the CP (c), whereas Constraint (2) ensures that each farm (f) will only be allocated to one CP (c). However, Constraint (3) determines the maximum capacity that the CP can have (maximum number of citrus farms that the CP (c) can serve). Constraints (4) and (5) ensure that each CP will be located close to the main street and that the distance between two sequential CPs will not be less than 1 km. Finally, the assumption in Equation (6) will ensure that each CP will have the same elevation as the main street in JV, as its altitude is approximately −200 m.

To run the model and extract the results, the Add-in OpenSolver was integrated into Microsoft Excel. As an initial step, we identified the maximum number of farms that a given CP can serve as 10, as illustrated in Constraint (3). The results showed that this solution is infeasible as all 102 CPs were fully occupied, and more than 957 farms were left without any assigned CPs. Therefore, Constraint (3) changed several times to reach a feasible solution starting from 20 farms assigned to each CP. The results from all iterations are summarized in Table 1.

Table 1. Results summary from all scenarios.

$\sum_{f=1}^{F} x_{fc} \leq F$	Number of CPs with a Maximum Capacity	Number of CPs with Less than the Maximum Capacity	Number of Un-Assigned Farms to CP	Notes
F = 10	102	0	957	Not feasible
F = 20	96	6	0	
F = 25	65	37	0	
F = 30	50	52	0	
F = 35	39	63	0	
F = 40	20	82	0	Best solution
F = 45	0	102	0	

However, when $\sum_{f=1}^{F} x_{fc} \leq 45$, none of the CPs were found at full capacity, and most of the CPs were allocated with fewer than 10 farms. Therefore, the best solution identified was when $\sum_{f=1}^{F} x_{fc} \leq 40$.

In the next step, the best solution was compiled in two stages to reduce the number of CPs. The model was run again after each stage, and the results are summarized in Table 1. After removing all CPs with an unfeasible number of farms, the total number of CPs is 52, where 46 of them will be working at the maximum capacity. The total time required to obtain the optimum solution was approximately 12 h.

2.2. Determining the Location of the Citrus Hub

As the citrus hub will be responsible for all logistics operations, its location must be feasible regarding total costs. However, one objective of this research is to improve the overall sustainability performance of CSC; therefore, the environmental impacts should be considered when finding the optimal location. The analyses were performed at two levels. The first was determining the initial location using the CoG methodology, which depends mainly on the amount of citrus supplied to the hub and the demand requested by the distribution centers. In the second level, the optimum location was determined based on the total transportation costs and the total CO_2 emission resulting from the inbound and outbound transportation processes.

2.2.1. Locating the Citrus Hub with the CoG

As a result of the CoG, the coordinate of the hub location is the main result. Prior to that, two steps should be conducted to apply Equations (7) and (8). These steps are: (i) identifying the coordinates of all CPs and their annual citrus; and (ii) identifying the demand and the coordinates of all DCs, which are proposed based on an interview with the general manager of one of the biggest supermarket series in Jordan, where they have at least one branch in each governorate, as listed in Table 2. However, to determine the demand for each governate, the CPC of each citrus product was multiplied by the population of each city of the 12 DCs. To find the coordinates of the CH, the following formulas were used:

$$X_{Hub} = \frac{\sum_{cp=1}^{CP} X_{cp}.Q_{cp} + \sum_{i}^{I} X_i.Q_i}{\sum_{cp=1}^{CP} Q_{cp} + \sum_{i}^{I} Q_i} \tag{7}$$

$$Y_{Hub} = \frac{\sum_{cp=1}^{CP} Y_{cp}.Q_{cp} + \sum_{i}^{I} Y_i.Q_i}{\sum_{cp=1}^{CP} Q_{cp} + \sum_{i}^{I} Q_i} \tag{8}$$

where:

Q_{cp}: Supplied citrus by a CP;
Q_{dc}: Demand for a DC;
(X_{dc}, Y_{dc}): coordinates of a DC;
(X_{hub}, Y_{hub}): coordinates of CH;
(X_{cp}, Y_{cp}): Coordinates of a CP.

Table 2. DC coordinates, their demand, and altitude.

		Demand (ton)						DC Location		
Governorate	**Population**	**Orange**	**Lemon**	**Clementine**	**Pomelo**	**Grapefruit**	**Demand Total**	**X**	**Y**	**Altitude**
Irbid	2,154,753	14,436.85	10,773.77	6033.31	754.16	754.16	32,752.25	32.535752	35.864732	596
Ajloun	166,036	1112.44	830.18	464.90	58.11	58.11	2523.75	32.299225	35.727012	779
Jerash	158,760	1063.69	793.80	444.53	55.57	55.57	2413.15	32.280825	35.894434	562
Almafraq	545,495	3654.82	2727.48	1527.39	190.92	190.92	8291.52	32.326029	36.219442	692
Zarqa	2,117,964	14,190.36	10,589.82	5930.30	741.29	741.29	32,193.05	32.086237	36.097935	594
Amman	467,7012	31,335.98	23,385.06	13,095.63	1636.95	1636.95	71,090.58	31.992909	35.934896	899
Madaba	122,008	817.45	610.04	341.62	42.70	42.70	1854.52	31.720194	35.803645	762
Alkarak	122,496	820.72	612.48	342.99	42.87	42.87	1861.94	31.113554	35.699169	1148
Tafilah	46,907	314.28	234.54	131.34	16.42	16.42	712.99	30.834886	35.618324	1028
Ma'an	62,640	419.69	313.20	175.39	21.92	21.92	952.13	30.51347	35.534352	1427
Aqaba	191,848	1285.38	959.24	537.17	67.15	67.15	2916.10	29.543969	35.014762	44
AlBalqa	247,881	1660.80	1239.41	694.07	86.76	86.76	3767.79	32.045385	35.741237	877

Based on Equations (7) and (8), the location of the citrus hub was identified with the following point: (X_{hub}, Y_{hub}) (32.2840046505103, 35.7900928362343). Figure 6 shows the exact location of the hub according to the CoG method. The advantages of this location are: (i) it is near the main road that connects Ajloun with Jerash, and (ii) it has direct access to the main road of JV.

2.2.2. Sustainable Location for the CH

A meeting with the Operation Manager of Masafat Specialized Transport (MST) company was conducted on 28 June 2022 to understand how they calculate the transportation costs, diesel consumption, and to consult them about the best location for such facility. MST is a trucking transportation company based in Amman.

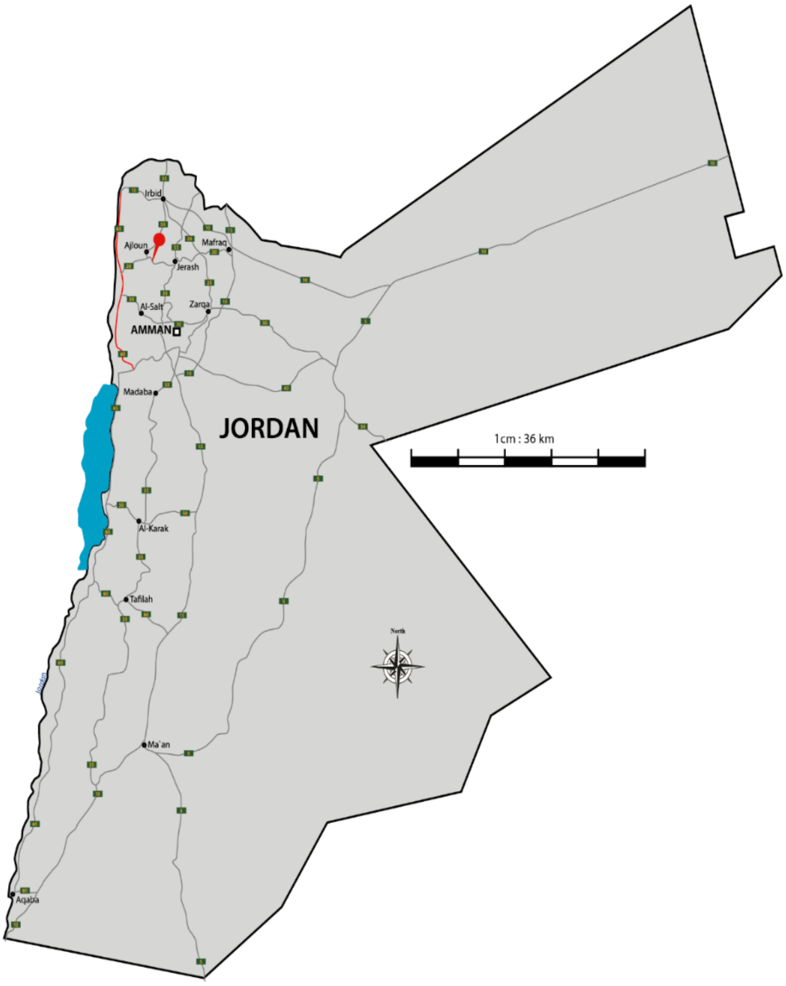

Figure 6. Citrus hub location based on center of gravity method (drawn by authors).

The feedback was: "if we consider a trailer loaded with a 40 ft container, the fuel consumption will be 1 L for each 2 km transferred. In addition to 1 L for every 10 m difference in the altitude of the initial and final points, including the return trips". Accordingly, the fuel consumption can be calculated as follows:

$$Fuel\ consumption = \frac{Distance\ (\mathrm{km})}{2\left(\frac{\mathrm{km}}{\mathrm{L}}\right)} + \frac{Altitude\ difference\ (\mathrm{m})}{10\ \left(\frac{\mathrm{m}}{\mathrm{L}}\right)} \quad (9)$$

Equation (9) is similar in concept to the model proposed by TNM [24], which was used to evaluate 14 locations (including the location determined by the CoG) identified according to the criteria of all proposed locations that must be close to one of the main streets in Jordan, as illustrated in Figure 7. The first location considered in the analysis is determined from CoG. Accordingly, the required data, such as distance from the main street of JV, distance from the reference point, coordinates, and altitude, were collected.

Coordinates of all suggested locations, all distribution centers, and the proposed CPs were gathered through the Google Maps application, whereas SolarGIS was used to collect the altitude data. Table 3 summarizes all this information for each suggested location for the citrus hub. Figure 7 shows the suggested geographic locations for the citrus hubs, which are considered in the evaluation, in which the suggested locations are marked with red points.

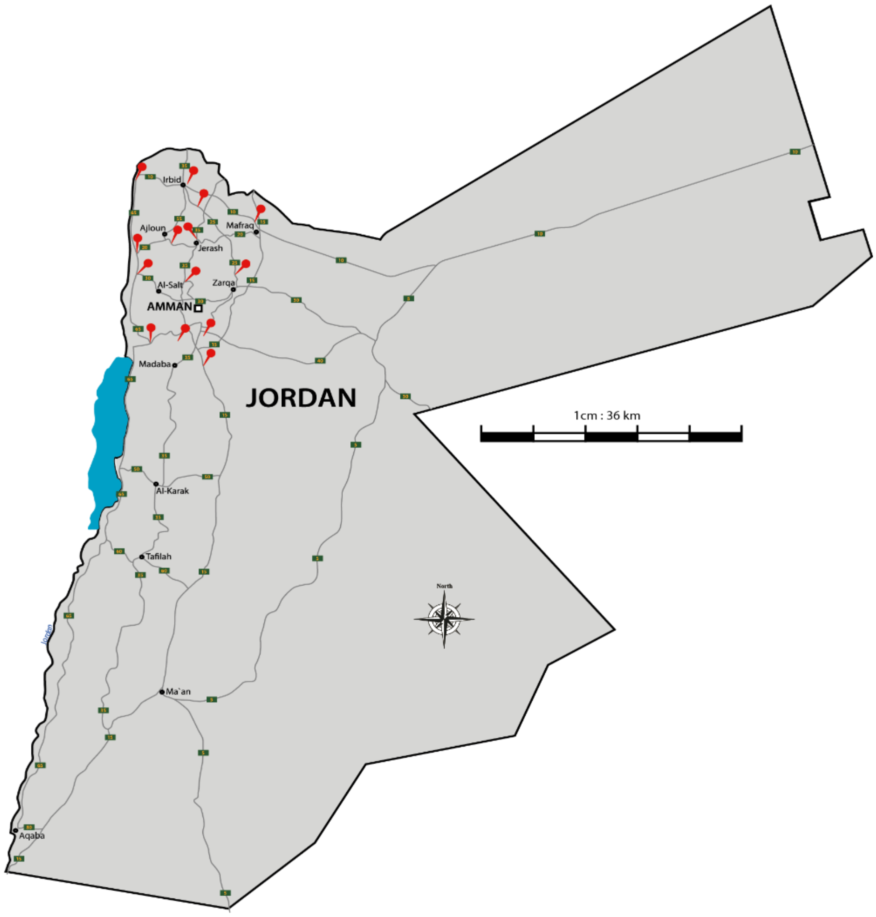

Figure 7. Geographic locations of the CH considered for the evaluation process (drawn by authors).

Table 3. Suggested locations for CH, their altitude, and the distance from JV.

Suggested Hub Locations					
Location	**X**	**Y**	**Altitude (m)**	**Distance from JV Main Street (km)**	**Distance from the Reference Point (km)**
1	32.585585	35.604645	−200	0	11
2	32.449214	35.933171	650	43.4	10
3	32.370443	36.214206	671	75	12
4	32.287735	35.917962	644	46	51
5	32.306916	35.763039	946	23	51
6	32.250747	35.608324	−200	0	51
7	32.142875	35.610514	−200	0	62
8	32.106092	35.84924	590	39	62
9	32.140241	36.108578	514	79	51
10	32.040545	35.786752	891	28	62
11	31.816399	35.648331	−200	0	102
12	31.860745	35.831702	920	21	102
13	31.71022	35.95193	710	50	102
14	32.285525	35.788576	1035	27.4	51

The sustainable location for the CH is evaluated based on the total transportation costs and the total CO_2 emissions. Therefore, the objective function was built to minimize the costs and CO_2 emissions based on minimizing the total diesel required to transport the citrus from farms to the distribution centers as follows:

$$minimize\ Z = \sum_{c=1}^{C} \frac{d_{cp}}{2} + \frac{\nabla a_{cp}}{0.1} + \sum_{dc=1}^{DC} \frac{d_{dc}}{2} + \frac{\nabla a_{dc}}{0.1} \quad (10)$$

where:

Z: Fuel consumption.
d_{cp}: Distance from a CP to the CH;
∇a_{cp}: Difference in altitudes of a CP and the CH;
d_{dc}: Distance from the CH to the distribution center a DC;
∇a_{dc}: Difference in altitudes of the CH and a DC.

3. Results and Discussions

The evaluation of the results based on Equation (10) shows a promising solution for selecting a location with fewer costs and environmental impacts. However, for a better understanding, Figure 8 compares the total diesel required to transport all citrus from farms to the suggested CH and then to the DCs, including the return trips with empty containers. The CM in location number 15 was added with all data about its location to compare the results with the current situation (marked in red). The red bar represents the total diesel required to transport all citrus from farms to CM and then to retailers from all provinces in Jordan.

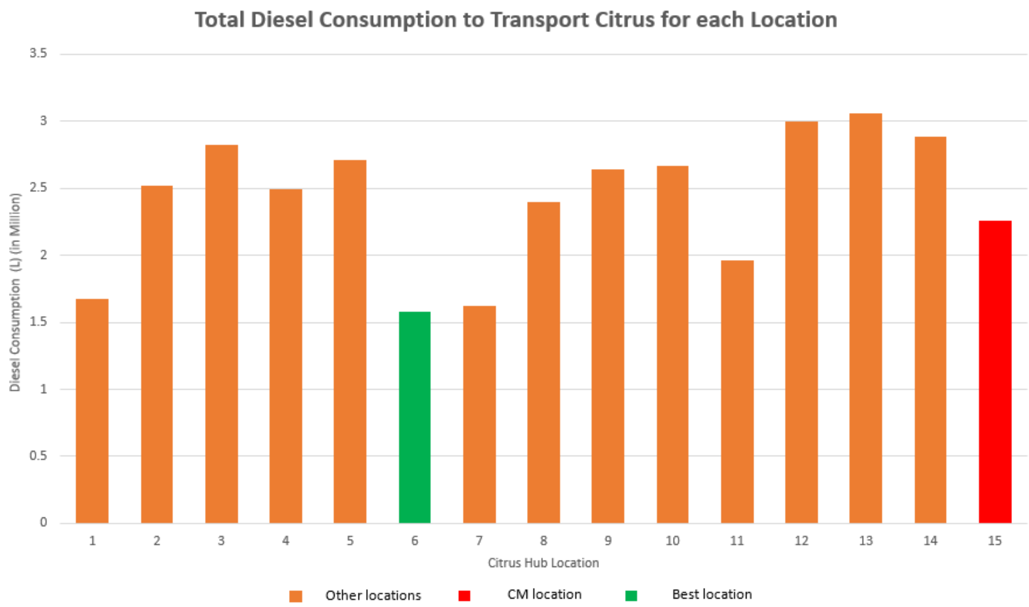

Figure 8. Total diesel needed to transport all citrus for the suggested locations, including the CM.

Moreover, the total diesel required for each location was multiplied by the costs/liter, which is 0.69 JOD/L, to calculate the transportation costs that will be paid for citrus transportation annually for each location. The total costs are illustrated in Figure 9, including the CM location (marked in red). Every CO_2 emission/L of diesel is about 2.64 kg CO_2/L [29,48]. The total CO_2 emissions can be calculated as we multiply the CO_2 emission/L of diesel by the total diesel consumed to transport all citrus. Figure 10 compares all locations in terms of total CO_2, including CM location (marked in red). When comparing the total CO_2 emission for location 6 (marked in green) to the CM location (marked in red), the total CO_2 was cut by 30.2%.

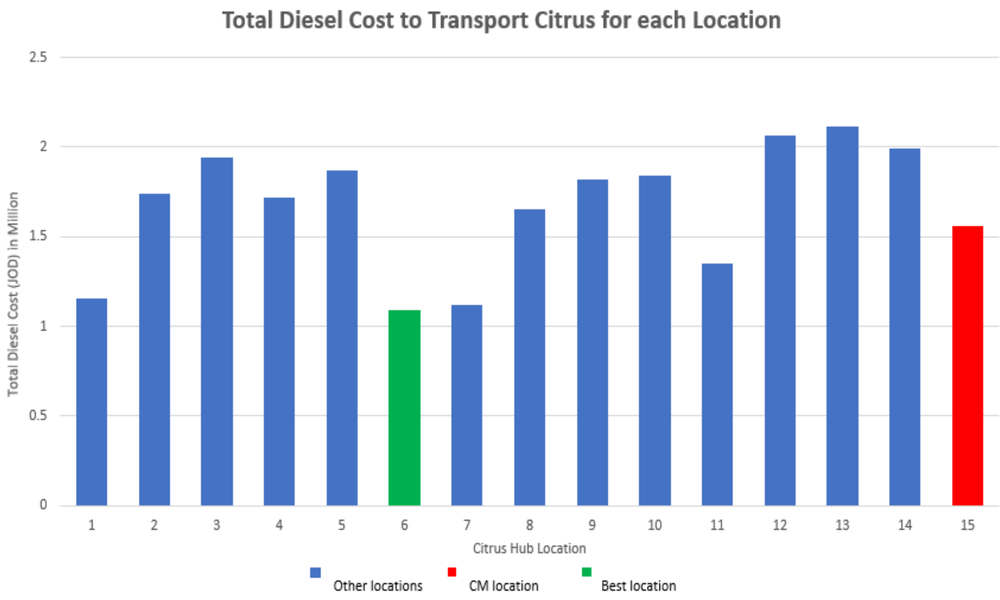

Figure 9. Total diesel costs to transport all citrus for the suggested locations, including the CM.

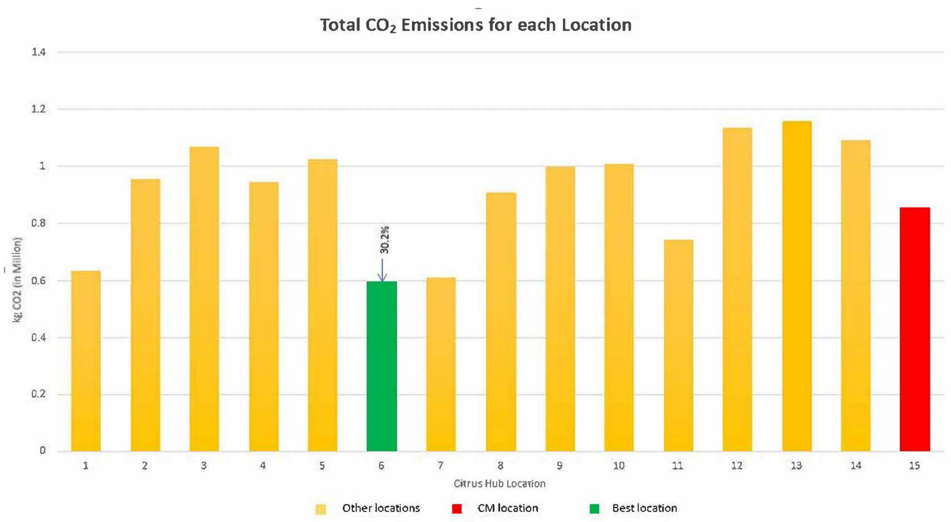

Figure 10. Total CO_2 emission resulting from diesel consumption annually for the suggested locations, including CM location.

Similarly, from Figures 8 and 9, location 6 showed higher potential to be selected than other locations in total transportation cost. When comparing the total CO_2 emission for location 6 (marked in green) to the CM location (marked in red), the total CO_2 was cut by 30.2%. Similarly, from Figures 8 and 9, location 6 showed higher potential to be selected than other locations in total transportation cost. In contrast, when we conducted the analyses to determine the best location based on the total CO_2 emissions, this location had one of the highest CO_2 emission values because of its altitude.

However, to enhance the CSC's flexibility and increase its responsiveness to the market, a similar analysis was conducted to decide on having two CHs instead of one hub. To save time and interact with the results shown in Figures 8–10, the included locations in the second round, which are 1, 6, 7, and 11, have the lowest total diesel consumption, transportation costs, and CO_2 emissions. Table 4 summarizes the included locations and possible combinations for each scenario. The analyses found that combination B is the best considering the total diesel consumption, total costs, and total CO_2 emissions, as illustrated in Figures 11–13, respectively.

Table 4. Two CHs combinations based on the lowest total diesel consumption and CO_2 emissions.

Citrus Hubs Combinations		
A	1	6
B	1	7
C	1	11
D	6	7
E	6	11
F	7	11

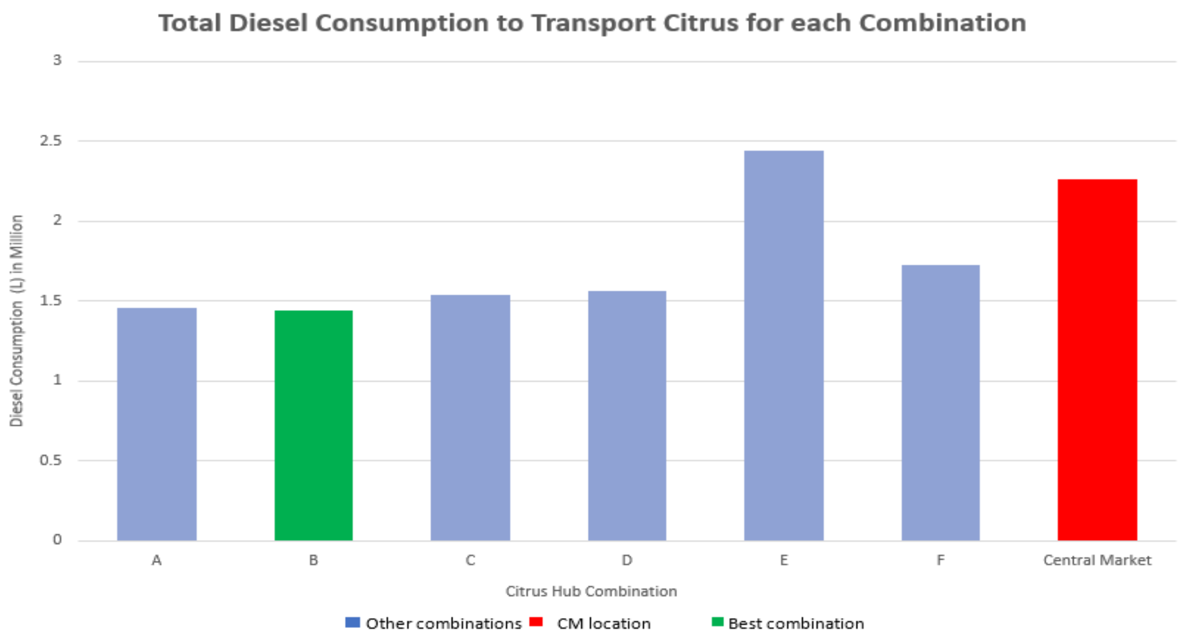

Figure 11. Total diesel needed to transport all citrus annually for all combinations, including CM location.

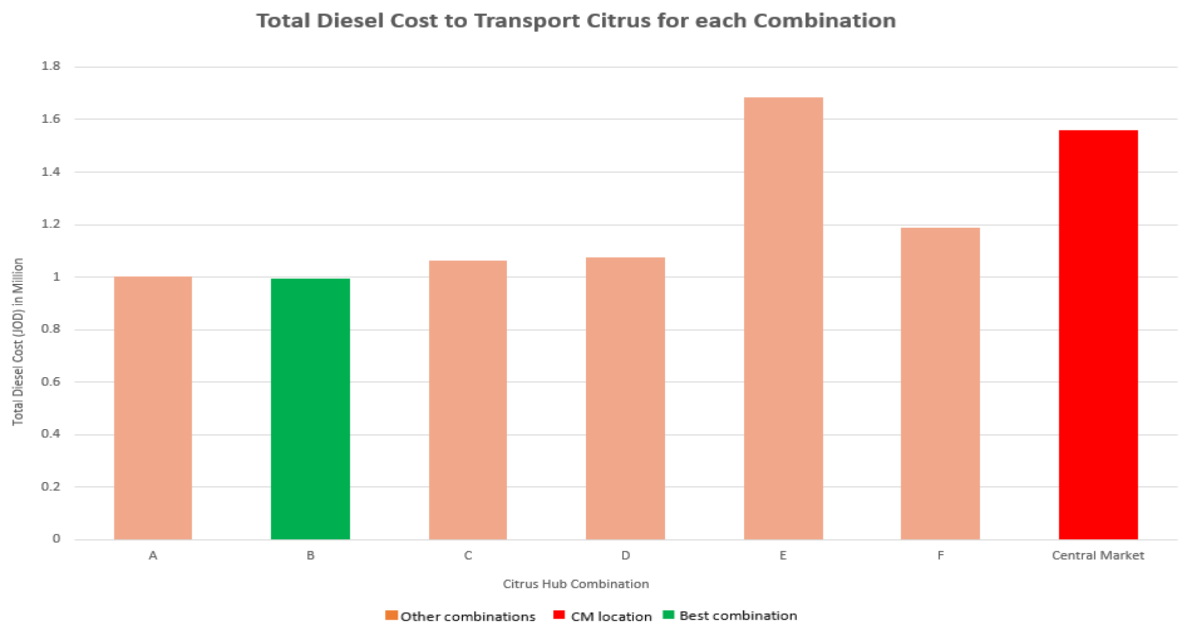

Figure 12. Total costs to transport all citrus for all combinations annually, including CM location.

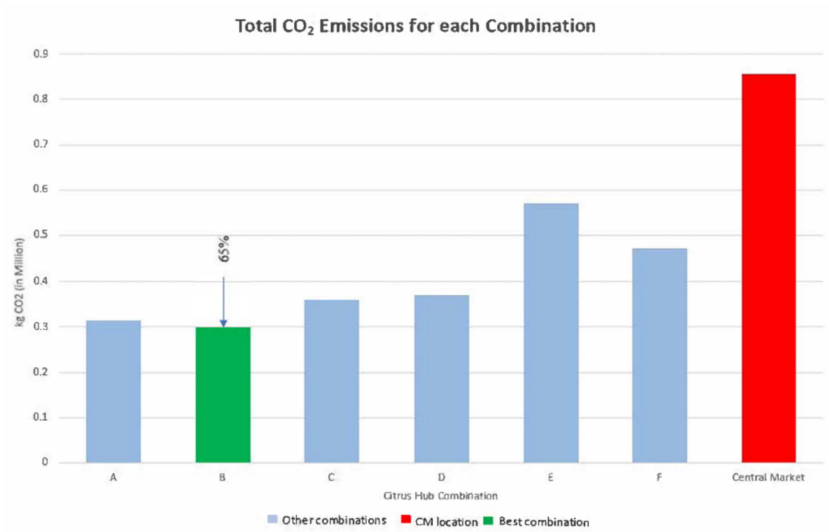

Figure 13. Total CO_2 emissions for all combinations annually, including CM location.

It can be seen that the total diesel required to transport all citrus has dropped by 36% compared with the CM location, which consequently has an impact on the amount of CO_2 savings. The CO_2 savings reached 65% for combination B compared to the CM location. Based on the results presented in Figures 11–13, there is a clear reduction in the total diesel required, costs, and CO_2 emissions when considering two CHs instead of only one as compared to Figures 8–10. Therefore, the rest of the analysis will consider the two hub scenario. It is intended that both hubs can distribute the citrus to the DCs equally based on the demand. In Table 5, we identified the CPs that will supply each hub and the DCs served by each hub according to the demand.

Table 5. Assigning CPs and distribution centers to each citrus hub.

DC	Average Demand	Number of Trips	Assigned CPs	Assigned Hub
Irbid	111.40	7.43	1–26	1
Ajloun	8.58	0.57		
Jerash	8.21	0.55		
Almafraq	28.20	1.88		
Zarqa	109.50	7.30		
Amman	241.80	16.12	27–52	2
Madaba	6.31	0.42		
Alkarak	6.33	0.42		
Tafilah	2.43	0.16		
Ma'an	3.24	0.22		
Aqaba	9.92	0.66		
AlBalqa	12.82	0.85		

Each hub was assigned to specific DCs based on the demand. The DCs assigned CH 1 were Irbid, Ajouan, Jerash, Almafraq, and Zarqa, with a total demand of 265.89 tons daily, whereas CH 2 was allocated to supply the DCs located in the southern part of Jordan in addition to Amman, with a total daily demand of 282.85 ton. To cover the required demands of each hub, CPs 1–26 were assigned to CH 1 based on distances and supplies. Similarly, CPs 27–52 were assigned to cover the demand for CH 2.

Comparing the results of having one or two CHs to the CM in terms of carbon footprint per 1 kg of citrus, it was found that having one CH in location 6 will reduce the CO_2 emission by 30.2%, around 0.48 kg CO_2 e/kg citrus. Interestingly, inserting two CHs in combination B will reduce the carbon footprint to reach 0.24 kg CO_2 e/kg citrus, a decrease of 65%, and combination A to reach 0.25 kg CO_2 e/kg citrus, a decrease of 63%. In contrast, the CM's current location was found to be 0.69 kg CO_2 e/kg citrus.

4. Conclusions

The study proposed a new CSC structure to help reduce CLW in Jordan. In addition, it also analyzed the CO_2 emission from transporting the citrus to the CM in terms of kg of CO_2 e/kg citrus; to compare this value with similar values from the optimum location for the new CHs. However, the data used were retrieved from diverse sources. For instance, Google Maps was used to collect the coordinates for the locations of citrus farms, CPs, and CHs, and the distances from one node to another, whereas SolarGIS was used to retrieve the altitude of the locations included in the analyses using the coordinates collected by Google Maps.

The included analysis found the locations based on minimizing the transportation costs while maintaining the associated CO_2 emissions at a low level. The resource allocation algorithm was used and solved using OpenSolver add-in to assign citrus farms to 52 CPs and determine their locations. In addition, CoG was used to find the initial location of a CH, which was evaluated along with 13 other suggested locations according to the total CO_2 emissions. Moreover, further analysis was conducted to decide on having more than one CH. However, the results revealed that having two CHs has the potential to reduce not only transportation costs but also total CO_2 emissions by 65%. When comparing it to one CH, it was reduced by 30.2%. In addition, the values of "kg CO_2 e/kg citrus" for CM, one CH, and two CHs were 0.69, 0.48, and 0.24, respectively. In addition, installing a CH in the location identified using CoG increases CO_2 emission due to its high altitude.

Practical and Managerial Implications

Implementing the results from the study would influence the overall sustainability performance. First, inserting the CHs in the locations provided in the study can provide local communities with job opportunities that will help reduce the unemployment rate in Jordan, which reached 24.7% by the end of 2021 [42]. In addition, the specified locations will reduce transportation costs as the total diesel required to transport the citrus from the cradle to the grave will be reduced and will minimize the total CO_2 emissions from citrus transport. The new structure of CSC provides an infrastructure to track and trace citrus products through its SC, which will improve the CSC's resilience. In addition, the proposed structure can be implemented to manage the reverse logistics operations and integrate circularity into the SC. The hubs can also be used for other agricultural products in JV. The CH can support other stakeholders in the SC by providing training courses for farmers and plans to improve agricultural practices to improve the quality of citrus and reduce CLW.

Future research might be directed to conduct further analysis to integrate the circular economy into the CSC, enhancing the economic performance measures and improving the associated environmental performance. Moreover, there is a need to study agricultural waste to provide a full waste valorization study that can help to find a feasible recovery method.

Author Contributions: Conceptualization, E.A.; Investigation, E.A.; Methodology, E.A.; Resources, E.A.; Software, E.A.; Supervision, B.N.; Validation, E.A.; Writing—original draft, E.A.; Writing—review & editing, E.A. and B.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. And The APC was funded by Universität Duisburg-Essen.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Miehle, W. Link-Length Minimization in Networks. *Oper. Res.* **1958**, *6*, 232–243. [CrossRef]
2. Labbe´, M.; Leal, M.; Puerto, J. New models for the location of controversial facilities: A bilevel programming. *Comput. Oper. Res.* **2019**, *107*, 95–106. [CrossRef]

3. Brandstätter, G.; Leitner, M.; Ljubi, I. Location of Charging Stations in Electric Car Sharing Systems Location of Charging *Stn. Electr. Car Shar. Syst.* **2020**, *54*, 1153–1438. [CrossRef]
4. Ahmad, D.; Bunayah, P.; Istiqomah, S.; Hisjam, M. Optimization of Network Design for Charging Station of Electric Car with Center of Gravity Method: A Case Study. In Proceedings of the Second Asia Pacific International Conference on Industrial Engineering and Operations Management, Surakarta, Indonesia, 13–16 September 2021; pp. 392–397.
5. Lin, Y.H.; Wang, Y.; He, D.; Lee, L.H. Last-mile delivery: Optimal locker location under multinomial logit choice model. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *142*, 102059. [CrossRef]
6. Neamatian Monemi, R.; Gelareh, S.; Nagih, A.; Maculan, N.; Danach, K. Multi-period hub location problem with serial demands: A case study of humanitarian aids distribution in Lebanon. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *149*, 102201. [CrossRef]
7. Nalan Bilişik, Ö.; Baraçlı, H. A binary fuzzy goal programming model with fuzzy parameters to select the fruits and vegetables market hall location for Istanbul. *Expert Syst. Appl.* **2023**, *211*, 118490. [CrossRef]
8. Altay, G.; Akyüz, M.H.; Öncan, T. Solving a minisum single facility location problem in three regions with different norms. *Ann. Oper. Res.* **2022**. [CrossRef]
9. Liu, X.; Guo, X.; Zhao, X. Study on Logistics Center Site Selection of Jilin Province. *J. Softw.* **2012**, *7*, 1799–1806. [CrossRef]
10. Cooper, L. Location–allocation problems. *Oper. Res.* **1963**, *11*, 331–343. [CrossRef]
11. Manzini, R.; Gebennini, E. Optimization models for the dynamic facility location and allocation problem. *Int. J. Prod. Res.* **2008**, *46*, 2061–2086. [CrossRef]
12. Torres-Sotoa, J.E.; Halit, Ü. Dynamic-demand capacitated facility location problems with and without relocation. *Int. J. Prod. Res.* **2011**, *49*, 3979–4005. [CrossRef]
13. Jiang, J.-L.; Yuan, X.M. A heuristic algorithm for constrained multi-source Weber problem–The variational inequality approach. *Eur. J. Oper. Res.* **2008**, *187*, 357–370. [CrossRef]
14. Liu, S.C.; Lin, C.C. A heuristic method for the combined location routing and inventory problem. *Int. J. Adv. Manuf. Technol.* **2005**, *26*, 372–381. [CrossRef]
15. Němec, P.; Stodola, P. Optimization of the Multi-Facility Location Problem Using Widely Available Office Software. *Algorithms* **2021**, *14*, 106. [CrossRef]
16. Bashiri, M.; Hosseininezhad, S.J. A fuzzy group decision support system for multi-facility location problems. *Int. J. Adv. Manuf. Technol.* **2009**, *42*, 533–543. [CrossRef]
17. Harris, I.; Mumford, C.L.; Naim, M.M. A hybrid multi-objective approach to capacitated facility location with flexible store allocation for green logistics modeling. *Transp. Res. Part E: Logist. Transp. Rev.* **2014**, *66*, 1–22. [CrossRef]
18. Jolai, F.; Tavakkoli-Moghaddam, R.; Taghipour, M. A multi-objective particle swarm optimisation algorithm for unequal sized dynamic facility layout problem with pickup/drop-off locations. *Int. J. Prod. Res.* **2012**, *50*, 4279–4293. [CrossRef]
19. Al-Haidary, M.; Ajlouni, M.A.; Talib, M.A.; Abbas, S.; Nasir, Q.; Basaeed, E. Metaheuristic Approaches to Facility Location Problems: A Systematic Review. In Proceedings of the 2021 4th International Conference on Signal Processing and Information Security (ICSPIS), Dubai, United Arab Emirates, 24–25 November 2021; pp. 49–52. [CrossRef]
20. Majhi, R.C.; Ranjitkar, P.; Sheng, M.; Covic, G.A.; Wilson, D.J. A systematic review of charging infrastructure location problem for electric vehicles. *Transp. Rev.* **2021**, *41*, 432–455. [CrossRef]
21. Klose, A.; Drexl, A. Facility location models for distribution system design. *Eur. J. Oper. Res.* **2005**, *162*, 4–29. [CrossRef]
22. Melo, M.T.; Nickel, S.; Saldanha-da-Gama, F. Facility location and supply chain management—A review. *Eur. J. Oper. Res.* **2009**, *196*, 401–412. [CrossRef]
23. Wolff, M.; Becker, T.; Walther, G. Long-term design and analysis of renewable fuel supply chains—An integrated approach considering seasonal resource availability. *Eur. J. Oper. Res.* **2023**, *304*, 745–762. [CrossRef]
24. Xifeng, T.; Ji, Z.; Peng, X. A multi-objective optimization model for sustainable logistics facility location. *Transp. Res. Part D Transp. Environ.* **2013**, *22*, 45–48. [CrossRef]
25. Martínez, J.C.V.; Fransoo, J.C. *Green Facility Location*; Sustainable Supply Chains. Springer Series in Supply Chain Management; Springer: Cham, Switzerland, 2017; pp. 219–234. [CrossRef]
26. Akcelik, R.; Besley, M. Operating cost, fuel consumption, and emission models in aaSIDRA and aaMOTION. In Proceedings of the 25th Conference of Australian Institutes of Transport Research (CAITR 2003), University of South Australia, Adelaide, Australia, 3–5 December 2003.
27. Eriksson, M.; Strid, I.; Hansson, P.A. Waste of organic and conventional meat and dairy products—A case study from Swedish retail. *Resour. Conserv. Recycl.* **2014**, *83*, 44–52. [CrossRef]
28. Alzubi, E.; Akkerman, R. Sustainable supply chain management practices in developing countries: An empirical study of Jordanian manufacturing companies. *Clean. Prod. Lett.* **2022**, *2*, 100005. [CrossRef]
29. Porat, R.; Lichter, A.; Terry, L.A.; Harker, R.; Buzby, J. Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. *Postharvest Biol. Technol.* **2018**, *139*, 135–149. [CrossRef]
30. Surucu-Balci, E.; Tuna, O. Investigating logistics-related food loss drivers: A study on fresh fruit and vegetable supply chain. *J. Clean. Prod.* **2021**, *318*, 128561. [CrossRef]
31. Göbel, C.; Langen, N.; Blumenthal, A.; Teitscheid, P.; Ritter, G. Cutting Food Waste through Cooperation along the Food Supply Chain. *Sustainability* **2015**, *7*, 1429–1445. [CrossRef]

32. Gogo, E.O.; Opiyo, A.M.; Ulrichs, C.; Huyskens-Keil, S. Nutritional and economic postharvest loss analysis of African indigenous leafy vegetables along the supply chain in Kenya. *Postharvest Biol. Technol.* **2017**, *130*, 39–47. [CrossRef]
33. Mena, C.; Terry, L.A.; Williams, A.; Ellram, L. Causes of waste across multi-tier supply networks: Cases in the UK food sector. *Int. J. Prod. Econ.* **2014**, *152*, 144–158. [CrossRef]
34. Chauhan, A.; Debnath, R.M.; Singh, S.P. Modelling the drivers for sustainable agri-food waste management. *Benchmarking* **2018**, *25*, 981–993. [CrossRef]
35. Jedermann, R.; Nicometo, M.; Uysal, I.; Lang, W. Reducing food losses by intelligent food logistics. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2014**, *372*, 20130302. [CrossRef] [PubMed]
36. Magalhães, V.S.M.; Ferreira, L.M.D.F.; Silva, C. Using a methodological approach to model causes of food loss and waste in fruit and vegetable supply chains. *J. Clean. Prod.* **2021**, *283*, 124574. [CrossRef]
37. Nicastro, R.; Carillo, P. Food Loss and Waste Prevention Strategies from Farm to Fork. *Sustainability* **2021**, *13*, 5443. [CrossRef]
38. Higgins, C.D.; Ferguson, M.R. *An Exploration of the Freight Village Concept and Its Applicability to Ontario*; McMaster University: Hamilton, ON, Canada, 2011; Available online: https://macsphere.mcmaster.ca/bitstream/11375/18911/1/MITL_Freight_Villages_January.pdf (accessed on 31 March 2022).
39. Snels, J.; Soethoudt, H.; Kok, M.; Diaz, J. Agrologistic Roadmaps Ghana. 2018. Available online: https://library.wur.nl/WebQuery/wurpubs/fulltext/471479 (accessed on 27 September 2022).
40. Cheraghalipour, A.; Paydar, M.M.; Hajiaghaei-Keshteli, M. A bi-objective optimization for citrus closed-loop supply chain using Pareto-based algorithms. *Appl. Soft Comput. J.* **2018**, *69*, 33–59. [CrossRef]
41. Roghanian, E.; Cheraghalipour, A. Addressing a set of meta-heuristics to solve a multi-objective model for closed-loop citrus supply chain considering CO_2 emissions. *J. Clean. Prod.* **2019**, *239*, 118081. [CrossRef]
42. Alzubi, E.; Noche, B. Improving Sustainability of Orange Supply Chain: A System Dynamics Model to Eliminating Pre-Harvesting Loss, Increase Workers, to Improve Farmer's Profit. In Proceedings of the International Conference on Industrial Engineering and Operations Management Istanbul, Istanbul, Turkey, 7–10 March 2022.
43. Hasan, S.; Haque, M.E.; Afrad, M.S.I.; Alam, M.Z.; Hoque, M.Z.; Islam, M.R. Pest Risk Analysis and Management Practices for Increasing Profitability of Lemon Production. *J. Agric. Ecol. Res. Int.* **2021**, *22*, 26–35. [CrossRef]
44. Ademosun, A.O. Citrus peels odyssey: From the waste bin to the lab bench to the dining table. *Appl. Food Res.* **2022**, *2*, 100083. [CrossRef]
45. FAO. Food Balances. Available online: https://www.fao.org/faostat/en/#data/FBS (accessed on 12 September 2022).
46. MoA. National Strategic Report 2021–2030. *Jordanian Minist. Agric.* **2021**, 1–52. Available online: http://www.moa.gov.jo/Default/Ar (accessed on 28 November 2021).
47. Alzubi, E.; Kassem, A.; Noche, B. A Comparative Life Cycle Assessment: Polystyrene or Polypropylene Packaging Crates to Reduce Citrus Loss and Waste in Transportation? *Sustainability* **2022**, *14*, 12644. [CrossRef]
48. Agrell, F.; Ablay, A. Developing An Innovative Unit of Power Supply to Improve the Sustainability of Data. 2022. Available online: https://www.diva-portal.org/smash/get/diva2:1674647/FULLTEXT01.pdf (accessed on 20 September 2022).