# A Review of Recent Research on Green Vehicle Routing Problem

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## Abstract

In today's world, environmental sensitivity increases with the overuse of energy and the increasing pollution in parallel with this situation, consistently. In this context, Green Vehicle Routing Problem attracts the attention of researchers as it is a scientific research problem that takes awareness of environmental impact and resource efficiency into account simultaneously. This paper investigates literature related to frequently used objective functions, constraints, fleet type, number of depots, parameter uncertainty and solution techniques in GVRPs. This study covers publications between 2011 and 2021 including 72 papers. The distinctness of this paper lies in highlighting the main features of GVRP that provide the direction of the development of researches.

## Keywords
Green Vehicle Routing Problem, Environmental Considerations, Literature Review.

## 1. Introduction

Today, as a result of human activities, the world is in a rapid technological change. While this change provides important advantages in people's life, it causes serious damage to the environment in another dimension. These generated environmental problems have ceased to be regional and threaten the future of living things on a global scale, so it has become a situation that remains the agenda of everyone. This situation has prompted to impose the legal and social sanctions to protect the natural environment. For this reason, businesses have tended to develop environmental policies. These sanctions directly affect road transportation in particular. Because the road transportation is one of the elements which causes most of the environmental issues like greenhouse gas (GHG) emissions, fuel consumption etc. in logistic sector. At this juncture, the concept of Green Logistics comes into view.

One of the types of problems that are examined within the scope of Green Logistics is Green Vehicle Routing Problem (GVRP). GVRP is a precious cost item for businesses since it optimizes the distribution network activities where constraints are created by considering environmental considerations while provided services to customers. Therefore, distribution networks which considers environmental objectives as well as economic benefits have been established in recent years. These established distribution networks and their vehicle routes are evaluated by many researchers and environmentalists.

The aim of this study is to conduct a literature review on studies dealing with Green Vehicle Routing Problem, frequently used objective functions and constraints, vehicle fleet type, number of depots, uncertainty of the models and solution methodologies. The scientific contributions of this literature review for academic researches: (1) It provides a detailed examination of studies considering GVRP and it is the most recent study due to this study covers studies which published in 2021 year. (2) This study examines the number of objective functions, the type of objective functions, the type of constraints, vehicle fleet type, the number of depot and parameter uncertainty used most in GVRP, separately and indicates what kind of mathematical model developed in the examined papers. (3) This study also analyzes in detail the types of solutions used in GVRP and which techniques are used within the scope of these solution types.

The present work is organized as follows. After this introductory section, the research methodology is presented in Section 2. Section 3 is devoted to a summary of the most important papers which include literature review. Section 4 contains a summary of the most relevant publications which consider mathematical models of green vehicle routing problem while Section 5 discusses detailed analyses and classifications of solution methodologies. Conclusions are drawn in Section 6.

## 2. Research Methodology

To survey the literature, the following six steps were applied within the scope of this research methodology.
(1) First, Academic databases such as Science Direct, Taylor & Francis, Springer Link which can be accessed online from university libraries were used.
(2) The English language was adopted to select the papers.
(3) Papers were filtered by using advanced search which includes keywords such as "Green Vehicle Routing Problem", "GVRP", "Environmental Considerations" and "Fuel Consumption".
(4) Since this study only focuses on GVRP, papers which contains Vehicle Routing Problem variants such as "Inventory Routing Problem" or "Pollution-Routing Problem" or "Location Routing Problem" were eliminated.
(5) Papers which do not contain mathematical models were also eliminated.
(6) Then, the bibliography of the literature reviews on GVRP prepared in previous years were reviewed. Reference papers on these studies were also considered according to the filter method.
With this methodology, we obtained 72 papers published between 2011 and 2021, from 32 journals. Figure 1 shows that the distribution of these articles according to the publish year and paper type. As the paper types, all papers were evaluated in three categories as "Review" or "Case Study" or "Computational Experiments". "Review" indicates the papers which include literature review. "Case study" indicates the papers which have case study related to the real world. "Computational Experiments" indicates that the papers have computational experiments which include benchmark instances taken from the literature.

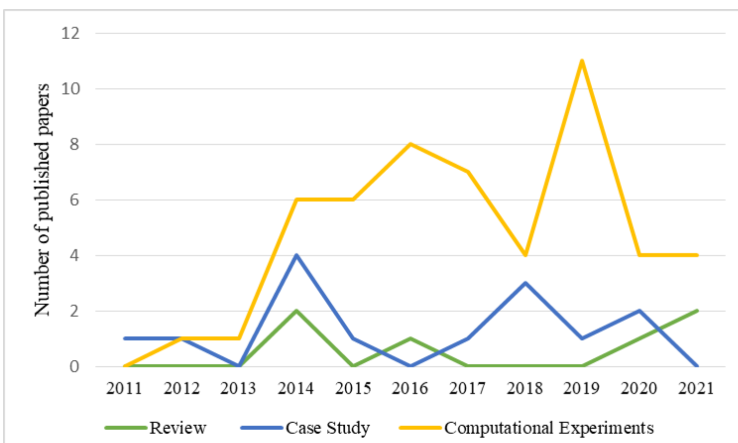


Figure 1: Publish date and type of the papers

Figure 1 highlights a clear trend and scientific contributions on Green Vehicle Routing Problem. As shown in the Figure 1, the green concept has gained growing attention in the scientific context, especially in last eight years. Figure 1 underlines this fact that almost 72 percent of the articles in the area of GVRP were written in the "Computational Experiments" category. "Case study" category follows this rate with 20 percent. And "Review" category has the rate 8 percent. It can be seen that the most articles were published in 2014 and 2019. In addition, “Review” articles have been on the rise for the last two years. So, Figure 1 shows that 72 papers published between 2011 and 2021 are reviewed in this paper that reflect the environmental consideration in routing problems and that this concern is increasing.

## 3. Literature Review

The most prominent aim of the Green Vehicle Routing Problem is achieving optimal routes through associating economic objectives with environmental ones. Due to the significant number of recent articles published in the domain of GVRP, a comprehensive literature review which focuses on GVRPs and their mathematical model is necessary. In this section, "Review" papers are examined in order to show this necessity. In Table 1, the "Review" papers, their spans and contents are found. To highlight the contribution of this research, these papers will be compared elaborately.

Table 1: Characteristics of "Review" papers

| No | Publication | Containing Years | Content |
|---|---|---|---|
| 1 | Demir et al (2014) | 2006-2013 | This paper focuses on a review of recent research on green road freight transportation. |
| 2 | Lin et al (2014) | 2006-2012 | This study provides a classification of GVRP that categorizes GVRP into Green-VRP, Pollution Routing Problem and VRP in Reverse Logistics. |
| 3 | Margaritis et al (2016) | 2008-2016 | This paper studies the use of electric commercial vehicles within the spectrum of green transport, and their key technical specifications. |
| 4 | Ferreira et al (2020) | 2012-2018 | This study provides a research conducted on the literature regarding Multi-objective optimization (MOO) for vehicle routing problems with Environmental Considerations. |
| 5 | Asghari and Mirzapour Al-e-hashem (2021) | 2000-2020 | This paper presents a classification scheme based on GVRP variants including internal combustion engine vehicles, alternative-fuel powered vehicles, and hybrid electric vehicles. |
| 6 | Moghdani et al (2021) | 2006-2019 | This paper studies variants of GVRPs, objective functions, uncertainty, and solutions approach. |

Demir et al (2014) have focused on fuel consumption models applied in freight transportation instead of examining green VRP from a general perspective. Lin et al (2014) have focused on the VRP variants including GVRP, Pollution Routing Problem and VRP in Reverse Logistics particularly. Margaritis et al (2016) have focused on the use of electric commercial vehicles within the spectrum of green transport, provided their key technical specifications and identified the main operating conditions that influence their effectiveness. Ferreira et al (2020) have provided a research conducted on the literature regarding for vehicle routing problems with environmental considerations. However, they only have focused on multi-objective optimization. Asghari and Mirzapour Al-e-hashem (2021) have investigated the main contributions related to the green vehicle routing problem and presents a classification scheme based on its variants considered in including internal combustion engine vehicles, alternative fuel powered vehicles, and hybrid electric vehicles especially.

Among all the considered studies in Table 1, the closest paper to this study belongs to Mogdani et al (2021). Moghdani et al (2021) have proposed an extensive structure compromising various aspects including variants of GVRPs, objective functions, uncertainty, and solutions approach to analyze GVRPs studies from different perspectives. However, this study includes articles written until 2019. On the other hand, this paper complicates the subject due to it contains VRP variants within itself. Due to this reason, a more specific literature search is needed for researchers who want to reach objective functions, constraints parameter types and solution methodologies that are generally used in GVRP. This paper provides a clearer study by focusing only on the previously created GVRP and their mathematical models. In addition, this study is more recent in contrast with the other papers, as it includes studies published this year. In this respect, it is expected that this study will make a significant contribution to the literature.

## 4. Mathematical Models of Green Vehicle Routing Problem

This section uses an integrated way to represents objective functions, common constraints, and related parameters of different Green Vehicle Routing Problem models. All papers were considered according to their objective functions, constraints, fleet type of vehicle, number of depot and uncertainty of their parameters. Therefore, this section sheds light on how the mathematical model of GVRP is generally designed, which constraints, objective functions and parameters are used in the mathematical model.

### 4.1 Objective Functions

Objective function is the one of the most important components of mathematical models for future research directions. To understand the objectives of GVRP, all papers (except "Review" papers) were evaluated considering their objective functions in this section. Frequently based objective functions are demonstrated in Figure 2. Figure 2 reveals that the reviewed papers split between two groups according to their objectives: single-objective and multi-objective. As can be seen, all papers consider the environmental and economical aspect of the vehicle routing problem.

Once the papers which have single objective considered, various scenarios reveal. Thus, many authors are concerned with minimizing distances or costs which includes environmental impacts such as emission cost (Erdoğan and Miller-Hooks 2012; Kwon et al. 2013; Felipe et al. 2014; Tajik et al. 2014; Zhang et al. 2014; Goeke and Schneider 2015; Soysal et al. 2015; Bruglieri 2016; Hiermann et al. 2016; Koç and Karaoğlan 2016; Koç et al. 2016; Yin and Chuang 2016; Jabir et al. 2017; Leggieri and Haouari 2017; Madankumar and Rajendran 2018; Niu et al. 2018; Soysal et al. 2018; Bruglieri et al. 2019a; Bruglieri et al. 2019b; Bruglieri et al. 2019c; Koyuncu and Yavuz 2019; Macrina et al. 2019a; Macrina et al. 2019b; Poonthalir and Nadarajan 2019; Dewi and Utama 2019; Fan et al. 2021) or minimizing the total travel time (Bruglieri et al. 2017;Shao and Dessouky 2020). Regarding the environmental aspect, a point in question is minimizing $CO_2$/GHG emissions ( Ubeda et al. 2011; Pradenas et al. 2013; Liu et al. 2014; Qian and Eglese 2014; Salimifard and Raeesi 2014; Tiwari and Chang 2015; Xiao and Konak 2016; Behnke and Kirschstein 2017; Kazemian and Aref 2017; Yu et al. 2019) in addition to fuel consumption (Li 2012; Küçükoğlu et al. 2015; Zhang et al. 2015; Rao et al. 2016; Kancharla and Ramadurai 2018; Olgun et al. 2021). When it comes to socail aspect of GVRP, the objective function includes minimizing total performance consist of noise level and exhaust emission (Ćirović et al. 2014).

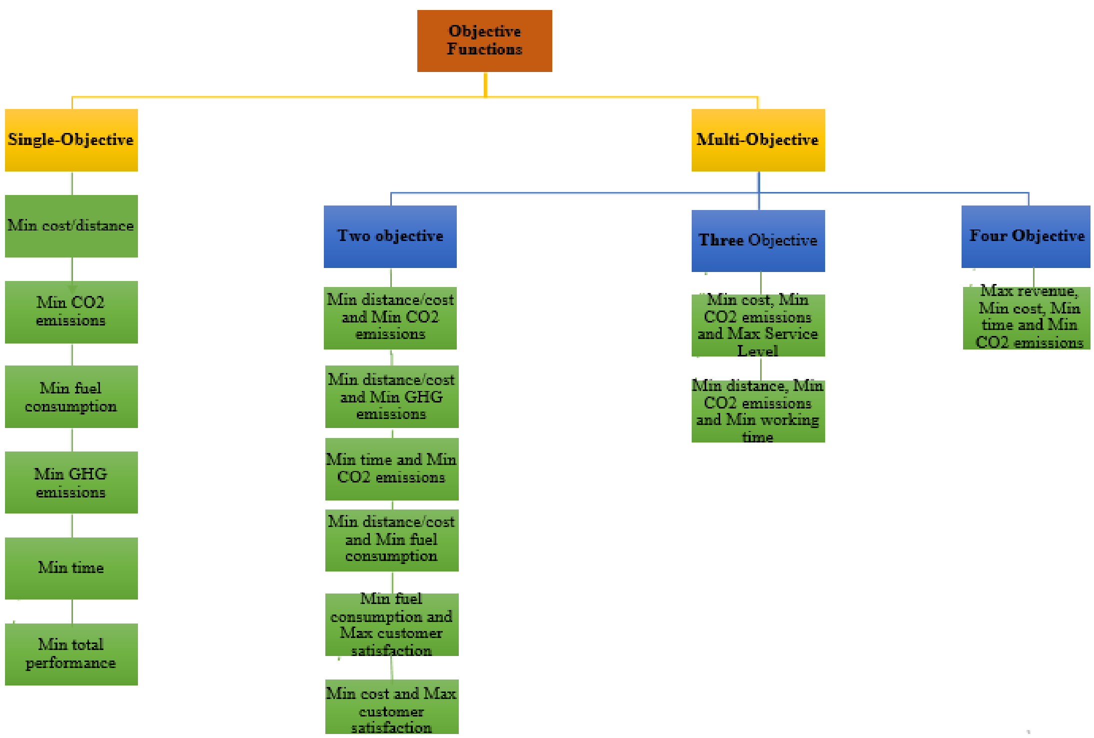


Figure 2: The framework of the objective functions in GVRP

Based on this study, a substantial amount of the latest literature on GVRP considers single-objective optimization. However, with the increasing importance of "green" concept in VRP, the necessity of considering environmental considerations as well as economic benefits shows up. At this point, authors focus on multi-objective optimization. As can be seen in Figure 2, multi-objective optimization subdivides into three categories. While some authors focuses on minimizing CO2/GHG emissions or fuel consumption besides distance/cost (El Bozuekri and El Hilali Alaoui 2014; Molina et al. 2014; Jabir et al. 2015; Gupta et al. 2017; Muñoz-Villamizar et al. 2017; Toro et al. 2017; Liu et al. 2018; Poonthalir and Nadarajan 2018; Soleimani et al. 2018; Wang et al. 2019; Giallanza and Puma 2020;

Poonthalir et al. 2020; Abdullahi et al. 2021), some authors take an interest in minimizing the time and emission/fuel consumption simultaneously (Xiao and Konak 2015; Kabadurmuş et al. 2019; Ren et al. 2020). Some authors consider social factors like minimizing total working time or maximizing customer satisfaction besides environmental and economic factors in their mathematical models (Ramos et al. 2014; Xu et al. 2019; Zulvia et al 2020; Niu et al. 2021). Within the scope of this study, only one paper have more than three objective functions consist of maximizing revenue, minimizing total cost, total time and total CO2 emissions (Li et al. 2019).

### 4.2 Constraints

To determine which constraints are used for GVRP generally, all papers were evaluated analyzing their constraints. Table 2 summarizes used objective functions, constraints, fleet type, number of depots and uncertainty of the parameters for all papers. As it is seen in Table 2 below, papers mostly include vehicle's capacity constraints, load constraints, arrival or departure time constraints, time window constraints, depot constraints, fuel tank capacity constraints (for papers which include Alternative Fuel Vehicles), battery capacity and charge level constraints (for papers which include Electric Vehicles), distance constraints and speed constraints within the scope of GVRP. These constraints were written as additional constraints by considering the attributes of the mathematical models. Besides, all mathematical models contain general VRP constraints such as flow conservation constraints, demand satisfaction constraints, sub tour elimination constraints and variable constraints by their types.

### 4.3 Fleet Type

Table 2 also shows the fleet classification (homogeneous or heterogeneous) through the sample papers. Although assuming a heterogeneous fleet can be more realistic, solving kind of these problems more complex than problems which have homogeneous vehicles. For this reason, more than half of the papers include homogenous fleet. Very few studies pay attention to the impacts of heterogeneous fleet on planning vehicle routes (Kwon et al. 2013; Liu et al. 2014; Molina et al. 2014;Hiermann et al. 2016; Koç et al. 2016; Xiao and Konak 2016; Yin and Chuang 2016; Behnke and Kirschstein 2017; Gupta et al. 2017; Muñoz-Villamizar et al. 2017; Soleimani et al. 2018; Koyuncu and Yavuz 2019; Macrina et al. 2019a; Macrina et al. 2019b; Yu et al. 2019; Ren et al. 2020; Shao and Dessouky 2020).

### 4.4 Number of Depots

In real life, some companies in the logistic sector may have several depots from which they can serve their customers. In such circumstances, Multiple Depot Vehicle Routing Problem should be considered. Table 2 indicates papers that involve multiple depots as well as single depot. When analyzed the Table 2, it can be seen that almost 80% of the papers have single depot. So, we can observe that only 14 articles in the sample address the Multi-depot VRP (Ramos et al. 2014; Jabir et al. 2015; Soysal et al. 2015; Koç et al. 2016; Jabir et al. 2017; Muñoz-Villamizar et al. 2017; Toro et al. 2017; Kancharla and Ramadurai 2018; Soleimani et al. 2018; Kabadurmuş et al. 2019; Li et al. 2019; Wang et al. 2019; Giallanza and Puma 2020; Fan et al. 2021).

### 4.5 Uncertainty of Parameters

Regarding various analyses, some parameters can be deterministic, and others considered nondeterministic or uncertain. Optimizing a mathematical model which includes uncertain parameters, can be more sophisticated since they may require a specific method. Table 2 comprises used uncertainty of parameters in the reviewed papers. In this context, the main parameters, considered uncertain in the Green Vehicle Routing Problem can include service time, travelling time, fuel consumption, $CO_2$ emission cost, vehicle speed, customer satisfaction, service level, demand, and so on. In addition to this, it can be seen that only 9 papers pay attention to the uncertain parameters in their mathematical models.

Table 2: The list of the papers according to the objectives, constraints, fleet type, number of depots and uncertainty

| No | Publication | Objective Function(s) | Constraint(s) | Fleet Type | Number of Depot | Uncertainty |
|---|---|---|---|---|---|---|
| 1 | Ubeda et al. (2011) | Min total $CO_2$ emissions | Capacity constraint, Time constraint | Homogenous | Single | No |
| 2 | Erdoğan and Miller-Hooks (2012) | Min total distance | Fuel tank capacity constraint, Time constraint | Homogenous | Single | No |
| 3 | Li (2012) | Min total fuel consumption | Capacity constraint, Time window constraint | Homogenous | Single | No |

| No | Publication | Objective Function(s) | Constraint(s) | Fleet Type | Number of Depot | Uncertainty |
|---|---|---|---|---|---|---|
| 4 | Kwon et al. (2013) | Min total cost | Capacity constraint, Carbon emission balance constraint | Heterogeneous | Single | No |
| 5 | Pradenas et al. (2013) | Min GHG emissions | Capacity constraint, Time window constraint | Homogenous | Single | No |
| 6 | Felipe et al. (2014) | Min total cost | Battery capacity constraint, Time constraint, Charge level constraint | Homogenous | Single | No |
| 7 | Ćirović et al. (2014) | Min total performance | Capacity constraint | Homogenous | Single | Costs are uncertain |
| 8 | El Bozuekri and El Hilali Alaoui (2014) | Min total distance, Min $CO_2$ emissions | Capacity constraint, Time window constraint, Schedule constraint | Homogenous | Single | No |
| 9 | Liu et al. (2014) | Min total carbon footprint | Capacity constraint, Time constraint | Heterogeneous | Single | No |
| 10 | Molina et al. (2014) | Min total cost, Min GHG emissions | Capacity constraint, Time constraint, Load constraint | Heterogeneous | Single | No |
| 11 | Qian and Eglese (2014) | Min GHG emissions | Capacity constraint, Time window constraint | Homogenous | Single | No |
| 12 | Ramos et al. (2014) | Min total distance, Min CO2 emissions, Min total working hours | Capacity constraint, Time window constraint, Multiple depots constraint | Homogenous | Multiple | No |
| 13 | Salimifard and Raeesi (2014) | Min total $CO_2$ emissions | Capacity constraint | Homogenous | Single | No |
| 14 | Tajik et al. (2014) | Min total cost | Capacity constraint, Time constraint, Load constraint | Homogenous | Single | Time and costs are uncertain |
| 15 | Zhang et al. (2014) | Min total cost | Capacity constraint, Load constraint | Homogenous | Single | No |
| 16 | Goeke and Schneider (2015) | Min total cost | Capacity constraint, Time window constraint, Charge level constraint | Homogenous | Single | No |
| 17 | Jabir et al. (2015) | Min $CO_2$ emissions, Min total cost | Capacity constraint Multiple depots constraint | Homogenous | Multiple | No |
| 18 | Küçükoğlu et al. (2015) | Min total fuel consumption | Capacity constraint, Time window constraint | Homogenous | Single | No |
| 19 | Soysal et al. (2015) | Min total cost | Capacity constraint, Time window constraint, Echelon flow constraint | Homogenous | Multiple | No |
| 20 | Tiwari and Chang (2015) | Min total $CO_2$ emissions | Capacity constraint | No informed | Single | No |
| 21 | Xiao and Konak (2015) | Min $CO_2$ emissions, Min total time | Time window constraint, Distance constraint | Homogenous | Single | No |
| 22 | Zhang et al. (2015) | Min total fuel consumption | Capacity constraint, Load constraint, Three dimensional constraint | Homogenous | Single | No |
| 23 | Bruglieri (2016) | Min total distance | Fuel tank capacity constraint, Time constraint | No informed | Single | No |
| 24 | Hiermann et al. (2016) | Min total cost | Capacity constraint, Time window constraint, Energy capacity constraint | Heterogeneous | Single | No |
| 25 | Koç and Karaoğlan (2016) | Min total distance | Fuel tank capacity constraint, Time constraint | Homogenous | Single | No |
| 26 | Koç et al. (2016) | Min total cost | Capacity constraint, Multiple depots constraint | Heterogeneous | Multiple | No |
| 27 | Rao et al. (2016) | Min total fuel consumption | Capacity constraint, Distance constraint | Homogenous | Single | No |
| 28 | Xiao and Konak (2016) | Min total $CO_2$ emissions | Capacity constraint, Fuel tank capacity constraint, Time window constraint, Distance constraint | Heterogeneous | Single | No |
| 29 | Yin and Chuang (2016) | Min total cost | Capacity constraint, Time constraint | Heterogeneous | Single | No |

| No | Publication | Objective Function(s) | Constraint(s) | Fleet Type | Number of Depot | Uncertainty |
|---|---|---|---|---|---|---|
| 30 | Behnke and Kirschstein (2017) | Min GHG emissions | Capacity constraint, Load constraint | Heterogeneous | Single | No |
| 31 | Bruglieri et al. (2017) | Min the sum of the differences between the ending and the starting time | Capacity constraint, Time window constraint, Charge level constraint | No informed | Single | No |
| 32 | Gupta et al. (2017) | Min total cost, Min CO emissions | Capacity constraint, Time constraint | Heterogeneous | Single | No |
| 33 | Jabir et al. (2017) | Min total cost | Capacity constraint, Multiple depots constraint | Homogenous | Multiple | No |
| 34 | Kazemian and Aref (2017) | Min GHG emissions | Capacity constraint, Time window constraint, Load constraint | No informed | Single | No |
| 35 | Leggieri and Haouari (2017) | Min total cost | Capacity constraint, Time window constraint, Energy capacity constraint | Homogenous | Single | No |
| 36 | Muñoz-Villamizar et al. (2017) | Min total cost, Min $CO_2$ emissions | Capacity constraint, Time constraint, Allocation constraint | Heterogeneous | Multiple | No |
| 37 | Toro et al. (2017) | Min total cost, Min $CO_2$ emissions | Capacity constraint, Load constraint, Location constraint | Homogenous | Multiple | No |
| 38 | Kancharla and Ramadurai (2018) | Min total fuel consumption | Capacity constraint, Load constraint | Homogenous Heterogeneous | Multiple | No |
| 39 | Liu et al. (2018) | Min fuel consumption, Min total cost | Capacity constraint | No informed | Single | No |
| 40 | Madankumar and Rajendran (2018) | Min total cost | Capacity constraint, Time window constraint, Fuel tank capacity constraint, Operations constraint | Homogenous | Single | No |
| 41 | Niu et al. (2018) | Min total cost | Capacity constraint, Time window constraint, Speed constraint | Homogenous | Single | No |
| 42 | Poonthalir and Nadarajan (2018) | Min fuel consumption, Min total cost | Fuel tank capacity constraint, Time constraint, Deviation constraint | Homogenous | Single | Speed is uncertain |
| 43 | Soleimani et al. (2018) | Min fuel consumption, Min total cost | Capacity constraint, Distribution center constraint, Multiple depots constraint | Heterogeneous | Multiple | No |
| 44 | Soysal et al. (2018) | Min total cost | Capacity constraint, Load constraint, Speed constraint | Homogenous | Single | No |
| 45 | Bruglieri et al. (2019a) | Min total distance | Time constraint, Path constraint | Homogenous | Single | No |
| 46 | Bruglieri et al. (2019b) | Min total distance | Time constraint, Fuel level capacity constraint | Homogenous | Single | No |
| 47 | Bruglieri et al. (2019c) | Min total distance | Time constraint, Fuel level capacity constraint | Homogenous | Single | No |
| 48 | Dewi and Utama (2019) | Min total cost | Capacity constraint | No informed | Single | No |
| 49 | Kabadurmuş et al. (2019) | Min $CO_2$ emissions Min the maximum travelling time | Time constraint, Fuel tank capacity constraint | Homogenous | Multiple | No |
| 50 | Koyuncu and Yavuz (2019) | Min total cost | Capacity constraint, Time window constraint | Heterogeneous | Single | No |
| 51 | Li et al. (2019) | Max revenue, Min total cost, Min travel time, Min CO2 emissions | Capacity constraint | Homogenous | Multiple | No |
| 52 | Macrina et al. (2019a) | Min total cost | Capacity constraint, Time window constraint, Energy capacity constraint, Fuel tank capacity constraint | Heterogeneous | Single | No |

| No | Publication | Objective Function(s) | Constraint(s) | Fleet Type | Number of Depot | Uncertainty |
|---|---|---|---|---|---|---|
| **53** | Macrina et al. (2019b) | Min total cost | Capacity constraint, Time window constraint, Battery capacity constraint, Pollution emission constraint | Heterogeneous | Single | No |
| **54** | Poonthalir and Nadarajan (2019) | Min total cost | Time constraint, Fuel tank capacity constraint | No informed | Single | No |
| **55** | Wang et al. (2019) | Min total cost, Min $CO_2$ emissions | Capacity constraint | Homogenous | Multiple | No |
| **56** | Xu et al. (2019) | Min fuel consumption, Max customer satisfaction | Capacity constraint, Time window constraint, Speed constraint | Homogenous | Single | Customer satisfaction is uncertain |
| **57** | Yu et al. (2019) | Min $CO_2$ emissions | Capacity constraint, Time window constraint, Load constraint | Heterogeneous | Single | No |
| **58** | Giallanza and Puma (2020) | Min total cost, Min $CO_2$ emissions | Capacity constraint, Fuzzy chance constraint, Distribution center constraints | Homogenous | Multiple | Demand is uncertain |
| **59** | Poonthalir et al. (2020) | Min total cost, Min $CO_2$ emissions | Time constraint, Fuel tank capacity constraint | Homogenous | Single | Speed is uncertain |
| **60** | Ren et al. (2020) | Min total emissions, Min total delay time | Capacity constraint, Time window constraint, Distance constraint | Heterogeneous | Single | No |
| **61** | Shao and Dessouky (2020) | Min total time | Time constraint, Fuel tank capacity constraint, Load constraint | Heterogeneous | Single | No |
| **62** | Zulvia et al (2020) | Min total cost, Min $CO_2$ emissions, Max service level | Capacity constraint, Time window constraint, Product's shelf life constraint | No informed | Single | Service level is uncertain |
| **63** | Abdullahi et al. (2021) | Min total cost, Min $CO_2$ emissions | Capacity constraint, Time window constraint, Fuel tank capacity constraint | Homogenous | Single | No |
| **64** | Fan et al. (2021) | Min total cost | Capacity constraint, Time constraint | No informed | Multiple | Fuel consumption is uncertain |
| **65** | Niu et al. (2021) | Min total cost, Max customer satisfaction | Capacity constraint | Homogenous | Single | Demand is uncertain |
| **66** | Olgun et al. (2021) | Min total fuel consumption | Capacity constraint, Time constraint, Pickup and delivery amount bound constraints | Homogenous | Single | No |

## 5. Solution Methodologies of Green Vehicle Routing Problem

Another dimension of this study is analyzing the characteristics of the algorithms used to solve the GVRP. Although there may be many other solution methodologies reported in the literature, Figure 3 illustrates the usage percentages and the main categories of solution methodologies, including exact algorithms, metaheuristics and heuristics.

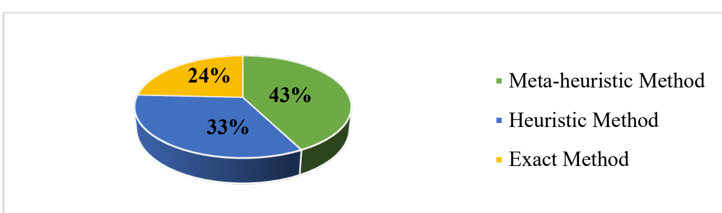


Figure 3: The percentage distribution of the solution methodologies used

The first category concerns metaheuristic algorithms. Figure 3 shows that the most used methodology is metaheuristics with ratio of 43 percent according to this literature review. The frequently employed metaheuristic methods in solving GVRP are: Tabu Search (Li 2012; Kwon et al. 2013; Niu et al. 2018; Dewi and Utama 2019), Simulated Annealing (Küçükoğlu et al. 2015; Xiao and Konak 2015; Koç and Karaoğlan 2016; Kazemian and Aref 2017), Genetic Algorithm (El Bozuekri and El Hilali Alaoui 2014; Liu et al. 2014; Fan et al. 2021), Adaptive Large Neighborhood

Search (Goeke and Schneider 2015; Koç et al. 2016; Shao and Dessouky 2020), Artificial Bee Colony (Zhang et al. 2014; Yin and Chuang 2016), Ant Colony Optimization (Jabir et al. 2015; Jabir et al. 2017), Particle Swarm Optimization (Poonthalir and Nadarajan 2018; Poonthalir et al. 2020), Matheuristic (Bruglieri et al. 2017; Macrina et al. 2019a) and Non-dominated Sorting Genetic Algorithm II (Xu et al. 2019; Giallanza and Puma 2020).

The second category remarks heuristic methods. These methods have been tailored for specific problems. Therefore, some authors have preferred to work with heuristic methods such as Local Search methods (Felipe et al. 2014; Zhang et al. 2015; Rao et al. 2016; Olgun et al. 2021), Neuro Fuzzy Model (Ćirović et al. 2014; Jovanović et al. 2014), Clarke and Wright Savings Heuristic (Erdoğan and Miller-Hooks 2012; Wang et al. 2019).

Another category in this dimension includes the use of exact methods, which are insufficient to solve a large-scale problem. Within this framework, some researchers have attempted to solve green vehicle routing problem using Mixed Integer Linear Programming with general exact solvers (Salimifard and Raeesi 2014; Tajik et al. 2014; Soysal et al. 2015; Bruglieri 2016; Hiermann et al. 2016; Behnke and Kirschstein 2017; Kazemian and Aref 2017; Leggieri and Haouari 2017; Toro et al. 2017; Kancharla and Ramadurai 2018; Madankumar and Rajendran 2018; Soysal et al. 2018; Bruglieri et al. 2019c; Kabadurmuş et al. 2019). Also, some authors have used Flagship algorithms, including branch and cut (Koyuncu and Yavuz 2019), branch and price (Yu et al. 2019).

## 6. Conclusion

In this study, a literature review is conducted on the studies based on Green Vehicle Routing Problem. The Review papers and other papers which contain mathematical models are examined, respectively. Then, the papers which have mathematical model are analyzed according to the objective functions, constraints, vehicle fleet type, number of depots and parameter uncertainty, separately.

According to the results, it can be seen that the objective functions frequently used in GVRP are cost minimization, $CO_2$/GHG emissions minimization and fuel consumption minimization. The most common constraints in the studies are vehicle capacity constraint, load constraint, time window constraint, fuel tank capacity constraint and battery level constraint. It is concluded that while the vehicles are homogeneous that are frequently used in terms of fleet type, single depot are preferred as the number of depots. The number of papers which have uncertain parameters is quite low in proportion to all papers. Meta-heuristics are the most commonly used methods for the solution of GVRPs. This is followed by heuristic methods and exact methods, respectively.

This study provides a recent and clear literature review for to be done scientific researches based on GVRP in the future. On the basis of the results obtained, various exact solution methods such as Branch and Cut, Branch and Price can be developed to find the optimal solution in the future works. In addition, fuzzy methods can be used in cases where the parameters of the problem are uncertain, and stochastic versions of the model can be studied. Sensitivity analysis can be performed by considering the homogeneous/heterogeneous vehicle fleet. Models can be developed for situations where more than one objective function is taken into account, and methods such as Epsilon-Constrained, AUGMECON can be used for their solutions. Most of all, never-before-seen integrated researches can be created by combining the Green Vehicle Routing Problem with other Supply Chain Management, Operations Management or Production Management issues.

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