Green Vehicle Routing Problem: A Review
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Abstract
In today’s highly competitive environment, Green-Vehicle Routing Problem (G-VRP) has received interest. G-VRP is a variant of Vehicle Routing Problem (VRP) is problematic in planning the vehicle routes with minimizing total distances traversed or total times taken while satisfying customers’ demands and other constraints. The challenge in G-VRP is the minimization of CO₂ emission in transportation sector. We provide a classification of G-VRP that categorizes G-VRP into Green-VRP, Pollution Routing Problem, and VRP in Reverse Logistics. This paper provides a review of recent research on G-VRP. The study covers the introduction of several changes into methodologies to solve vehicle routing problems with environmental criteria (Green House Gas emission, Fuel Consumption etc) minimization.

Keywords
GNR TFET, Sub-threshold swing, ON/OFF Current ratio

I. INTRODUCTION
Environment pollutants have been increasing day by day and one of the major parts of it is air pollution. Green VRP has recently received increasing and close attention from governments and business organizations. To respond to this challenge, the United Nations, the European Union, and many countries have enacted legislations to control CO₂ emissions [1]. Some companies, like IEKA, HP, IBM and GE, also begin to proactively implement ‘green’ initiatives, such as designing greener products or re-optimizing their supply chain networks [2]. The environmental, ecological and social effects are taken into consideration when designing models, in addition to the conventional economic costs. The greenhouse effects play an important role worldwide with many laws and regulations to reduce greenhouse gas pollution has already been passed that have strong effects on the logistics industry. The traditional Vehicle Routing Problem (VRP) is a combinatorial optimization and integer programming problem which asks “What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?” The Green Vehicle Routing Problem is actually Vehicle Routing Problem with some eco-friendly strategies. The green VRP mainly concerns about the environmental effects of different distribution strategies, reducing the energy consumption, recycling refuse and managing waste disposal [3]. Transportation technologies and fuels have improved over the years, most trucks run on diesel engines, which are major sources of emissions of nitrogen oxides (N₂O), particulate matter (PM) and carbon dioxide (CO₂). Repeated exposure to N₂O-based smog and PM has been linked to a wide range of health problems. At the global level, greenhouse gases (GHGs) significantly contribute to global warming. In the transportation sector, GHG emissions are dominated by CO₂ emissions from burning fossil fuels. These cause atmospheric changes and climate disruptions which are harmful to the natural and built environments and pose health risks. Logistic companies may use optimization methods to improve route planning, which helps to decrease the travelled distance of their vehicles and hence emissions. Researchers tend to pay close attention to the role that transportation will play in achieving positive environmental effects. Exploring the relationship between environmental effect and transportation through route planning will be able to provide practical and valuable suggestions regarding this green logistics campaign.

II. FUNDAMENTALS ON VRP
The root of VRP strategies is Travelling Salesman Problem. In 1736 Leonard Euler invented this problem. The first TSP paper published on 1920’s. Travelling-Salesman Problem is concerned with the determination of the shortest route which passes through each of n given points once. Assuming that each pair of points is joined by a link, the total number of different routes through n points is 2ⁿ⁻¹. We can see the use of TSP in - Vehicle routing problem, Scheduling jobs on machines, Manufacture of microchips, Computing DNA sequences, Designing telecommunications networks, Designing and testing VLSI circuits, X-ray crystallography, Clustering data arrays.

\[
\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij} \quad (1)
\]

Subject to:
\[
\sum_{i=1}^{n} x_{ij} = 1 \quad \forall \ i \quad (2)
\]
\[
\sum_{j=1}^{n} x_{ij} = 1 \quad \forall \ j \quad (3)
\]
\[
x_{ij} + x_{jk} \leq 1 \quad \forall \ i,j \quad (4)
\]
\[
x_{ij} + x_{jk} + x_{kl} \leq 2 \quad \forall \ i,j,k \quad (5)
\]
\[
x_{ij} = 0 \text{ or } 1 \quad (6)
\]

In 1959 Dantzig and Ramser added a new constraint “Capacity” with Travelling Salesman Problem, and introduced Vehicle Routing Problem [4]. The name of their paper was "The Truck Dispatching Problem". In the problem as formulated above it was assumed that at every station point a demand for certain products were specified and that this demand must be satisfied by one delivery. By relaxing the condition that demand must be satisfied in full, it may be possible to reduce total truck mileage still further. In their truck dispatching problem, the capacity of each truck is explicitly considered (Capacitated VRP, CVRP). In the light of the properties of cost in the matrix of distance, CVRP can
be further partitioned into Symmetrical CVRP (SCVRP) and Asymmetrical CVRP (ACVRP)[5].

Minimize \[ Z = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{k} c_{ij} X_{ijk} \]  

Subject to :

\[ \sum_{h=0}^{n} d_{ih} = l_i \quad \forall \ h \quad (2) \]
\[ \sum_{i=1}^{n} Y_{ih} = 1 \quad i = 1,2,...,n \quad (3) \]
\[ \sum_{i=0,i\neq j}^{n} X_{ijh} = Y_{ih} \quad j = 1,2,...,n \quad \forall \ h \quad (4) \]
\[ \sum_{j=0,i\neq j}^{n} X_{ijh} = Y_{ih} \quad i = 1,2,...,n \quad \forall \ h \quad (5) \]
\[ X_{ijh} = 0 \text{ or } 1 \quad i,j = 1,2,...,n \quad \forall \ h \quad (6) \]
\[ Y_{ih} = 0 \text{ or } 1 \quad i,j = 1,2,...,n \quad \forall \ h \quad (7) \]

VRP has enjoyed close and extensive research attention for nearly 50 years. A variety of survey papers were published at different times up to that date (Figure 2). After adding many constrains and real life application we have got these VRP variants –

a. **Time-dependent Vehicle Routing Problem (since 1966)** - Cooke and Halsey extended the classical shortest path problem with static intermodal to consider varying intermodal time [6]. Multiple vehicles were not considered in this study. Malandraki and Daskin gave the mixed integer linear programming mathematical model of TDVRP [7] and its special case, TDTSP. The property of Time-dependent VRP (TDVRP) is that the travel time between any pair of points (customers and depots) depends on the distance between the points or on the time of day (e.g. rush hours, weather conditions). Solomon and Finghiozzi introduced the benchmark problems in TDVRPTW (TDVRP with Time Windows) to evaluate and compare the solution quality and computational time of the algorithms in this field[8,9]. Chen et al., Kritzinger et al. and Soler, Albiach, Martinez also have research work in this field [10]. Euclidean distance has been assumed as a constant in VRP. But in real life experiment it does not work. In neglected the relation between cost variable and time and introduced TDVRP [11]. Lecluyse, Sörensen, & Peremans shows the recurring traffic congestion problems can be solved by using TDVRP [12]. In 2012 Kok, Hans, & Schutten discovers the solution techniques [13].

b. **Pickup and Delivery Problem (since 1967)** - Wilson and Weissberg examined Pickup and Delivery Problem (PDP) to solve a dial-a-ride problem [14]. VRP with backhauls, VRP with pickup and delivery, VRP with simultaneously pickup and delivery, dial-a-ride problem, etc. are different solving methodologies in this. Some of them have very similar structure of the nature of the problem but have slight differences, so they are difficult to distinguish and cause confusion. Parragh, Doerner, and Hart provided literature synthesis for PDP and gave a very reasonable classification of PDP[15]. According to their literature, the subcategories are shown in figure 1 -

c. **Multi-depot VRP (since 1969)** - Earlier VRP have a restriction that is, every vehicle route must start and end at the same depot. Tillman (1969) firstly studied Multi-depot VRP (MDVRP). It contains more than one depot and each customer is visited by a vehicle that is assigned to one of these depots. MDVRP used in a lot of physical distribution problems such as the delivery of meals, chemical products, soft drinks, machines, industrial gasses, packaged food, etc. Various extensions of MDVRP are discussed in literatures, including MDVRP with Time Windows [16], MDVRP with Backhauls [17], MDVRP with Pickup and Delivery [18], Multi-depot Location Routing Problem [19], MDVRP with Loading Cost [20], MDVRP with Inter-depots [21], MDVRP with Mix Fleet [22].

d. **Stochastic VRP (since 1969)** - Gendreau et al. (1969) provided an extensive survey on Stochastic VRP (SVRP)[23]. SVRP arises where elements in the routing problem are random. Probability theory is used to build mathematical models when problems represent uncertainty. SVRP can be categorized into different variants: VRP with Stochastic Demand and Travel Time [24], VRP with Stochastic Demand [25], VRP with Stochastic Customers [26], VRP with Stochastic Customers and Demands[27], VRP with Stochastic Travel Time [28], VRP with Stochastic Travel Time and Service Time [29].

e. **Location Routing Problem (since 1973)** - Separated design of depot location and vehicle routing cause suboptimal solution and generates extra cost, which motivates to invent a Location Routing Problem (LRP) [30]. LRP consist designing of a single or a set of depots and a number of routes for each opened depot. The objective is to minimize the overall cost comprising the fixed costs of opening the depots and the costs of the routes. The application of LRP can be found in waste collection, post-box location, parcel delivery, mobile communications access networks, and grocery distribution. Baldacci et al.; Belenguer et al; Nagy and Salhi ; Srivastava et al provide reviews on LRP [31].

f. **Periodic VRP (since 1974)** - An algorithm is developed by Beltrani and Bodin to solve routing

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**Fig.1 Subcategories of Pickup and Delivery Problem [15]**
problems, in which locations or customers’ required different numbers of visits and different day combinations for visits in a certain time [32]. The classical VRP is extended not only to determine a shortest route but also to assign the tours to certain days of the week. The objective of Periodic Vehicle Routing Problem (PVRP) is to find a feasible routing solution such that the total cost of the routes over the time is minimized. The significant studies on PVRP are - picking up raw materials from suppliers [33], allocation of workforce [34]. PVRP with Multi-depot PVRP [35], PVRP with Service Choice [36], PVRP with Time Windows [37], Site-dependent Multi trip PVRP [38].

g. **Dynamic VRP (since 1976)** - The traditional VRP does not deal with uncertain circumstances of the real-world such as breakdown of vehicles, traffic control, continually arriving customer requests etc. Dynamic VRP (DVRP) is featured by the ongoing fashion in which the information such as vehicle locations, customer orders (online requests) are revealed over certain time period and assigned in real time to appropriate vehicles. Speidel (1976) first introduced Dynamic VRP [39]. Various classes of DVRP with different aspects categorized: DVRP with Time Windows [40] and DVRP with Pickup and Delivery and Time Windows [41]. The overview of DVRP with its application and algorithm - Angelelli et al.; Bertsimas; Gendreau; Ghiari et al. (2003); Ghiarni, et al.; Li, et al.; Mu et al.; Pillac, Gendreau, Guéret, and Medaglia (2012)[42,43].

h. **Inventory Routing Problem (since 1984)** - Inventory routing problems (IRPs) deal with not only routing but also inventory decisions for a single model. IRPs are considered as difficult problems, so many heuristic approaches were proposed in the previous literatures. Bell et al. firstly consider a heuristic approach for solving multi-period IRPs [44]. After several efforts for finding ways to solve different types of IRPs, Andersson, Hoff, Christiansen, Hasle, and Løkketangen gave a classification and comprehensive literature review of the current state of the research from industrial aspects of combined inventory management and routing in maritime and road-based transportation[45]. Richard modelled a specific inventory routing problem in which goods are perishable (PIRP) [46], and they exploit the model structure to develop a column generation-based solution approach. Federgruen et al. firstly integrate transportation and inventory models for perishable goods [47]. Tarantilis and Kiranoudis developed a threshold-based algorithm for solving the fresh milk distribution problem for one of the biggest dairy companies in Greece [48]. Giri and Chaudhuri proposed a deterministic models of perishable inventory with stock-dependent demand rate and nonlinear holding cost, and the holding cost were treated as two situations, the approximate optimal solution in both cases were derived[49].

Dror, Ball, & Golden; Dror & Levy; Dror & Ball; Speranza ; Archetti, Bertazzi, Laporte, and Speranza ; Zhao, Chen, and Zang provides Implications of trends both in industry and research [50].

i. **Fleet Size and Mix Vehicle Routing Problem (since 1984)** - Fleet Size and Mix VRP considers problems where different types of vehicles are available. It was first introduced by Golden et al.[51]. He identifies five major sub classes differing in the number of vehicles available (limited, unlimited), whether a fixed cost per vehicle is considered or not and if the routing cost depend on the vehicle type, the original formulation considers an unlimited number of vehicles with fixed acquisition costs and vehicle type independent routing costs, which is classified as a Fleet Size and Mix VRP with Fixed costs (FSMF)[52]. FSMVRP with Time Windows has been well studied as an extension of FSMVRP. FSMVRP with Multi-depot is another natural extension of FSMVRP. Dondo and Cerda considered a combined multi-depot and time window version in FSMVRP [53].

j. **Generalized VRP (since 1984)** - Tsiligirdes introduced Generalized VRP in 1984. In 1996 Chao, Golden, and Wasil extended orienteering problem [54]. In Generalized VRP, the customers are partitioned into clusters and vehicles are obligated to visit only one customer in each cluster, each cluster should be visited exactly once [55]. Prize collecting travelling salesman problems [56]; the selective travelling salesman problem [57]; the travelling salesman problem with profits [58]; VRP with selective backhauls provided an exhaustive survey on Generalized VRP [59].

k. **Multi-compartment VRP (MCVRP) (since 1985)** - As customers have to be delivered by a vehicle with multiple compartments, MCVRP are inhomogeneous and non-intermixable. In MCVRP, each customer can request one or more types of products[60]; all products must be delivered by only one vehicle. Multiple visits are also allowed to deliver different requested products so as to fulfill the demand set of products. Different types and qualities of multi-compartment VRP can be found in the work of Muylkemans and Pang ; Oppen and Løkketangen Chajakis and Guignard ; Bukchin and Sarin ; El Fallahi, Prins, and Wolfler Calvo ; Mendoza et al. [61].

l. **Site-dependent VRP (since 1986)** - Site-dependent VRP introduced by Nag, in 1986. Site-dependent VRP compatible with customers and vehicle types,
each customer is allowed to be visited by only one set of vehicle types. One customer has to select only one type of this set of allowable vehicle types. Many real-life application problems, such as refuse collection[62], grocery delivery[63], pet food and flour distribution [64], After-sales service, Site-dependent VRP was mentioned as a variant of the general heterogeneous VRP in reference [65].

m. **Split-delivery VRP (SDVRP) (since 1989)** - Sometimes the demand of customers exceeds the vehicle capacity. Split delivery VRP allows serving each customer by more than one vehicle. Dror and Trudeau demonstrated that remarkable cost savings with regard to the number of vehicles utilized and the total traveling distance can be achieved by split deliveries. Archetti, Savelsbergh, and Speranza showed that the savings can reach up to 50%. SDVRP with Time Windows is the main extension of SDVRP [66].

n. **Fuzzy VRP (FVRP) (since 1995)** - Fuzzy logic is used to formulate the uncertain, subjective, ambiguous, and vague elements. The fuzzy membership function reflects the degree of customer satisfaction of service time like “15:00 to 18:00 is highly preferable for delivery”. VRP with Fuzzy Time Windows (VRPFTW) concerns about how service time preference influences the service level. Cheng, Gen, and Tozawa replaced fixed time window with a fuzzy due-time. Tang, Pan, Fung, and Lau considered linear and concave fuzzy membership functions for the fuzzy soft time window and formulated a multi-objective model for the VRPFTW [67]. Other versions of FVRP are VRP with Fuzzy Demand and VRP with Fuzzy Travel Time [68].

o. **Open VRP (OVRP) (since 2000)** - Earlier all the vehicles have to return to the depot after servicing all the affiliated customers. In 2000, Sariklis and Powell removes this restriction. Open VRP is useful in real-world cases, such as the delivery of school meals, school bus routing, the plans of passing through tunnels of trains, the newspaper or mail delivery service, companies that outsource the deliveries to the third party logistics provider (3PL) as the external vehicles are not obligated to return to the depot etc. Brandão proposed a tabu search for OVRP [69]. Li, Golden, and Wasil provided a survey on the algorithms of the OVRP [70]. Repoussis, Tarantilis, and Ioannou added OVRP with Time Windows. Li, Leung and Tian searches on heterogeneous fixed fleet OVRP [71].

p. **VRP with Loading Constraints (VRPLC) (since 2003)** - VRP with Loading Constraints (VRPLC) determines both the optimal routes and packing patterns. A travelling salesman problem with pickup and delivery and Last-In-First-Out (LIFO) loading constraint presented by Ladany and Mehriz (1984)[72]. In Two-dimensional Capacitated VRP (2L-CVRP), customer demand consists of rectangular two-dimensional weighted items. Extensions of VRPLC include Two-dimensional Pickup and Delivery Routing Problem [73], Three-dimensional Capacitated VRP [74], Vehicle Routing with Time Windows and Loading Problem [75], Multi-Pile Routing Problem, The Pallet-Packing Vehicle Routing Problem, Pickup and Delivery TSP with LIFO Loading [76].

q. **Multi-echelon VRP (since 2009)** - Multi-echelon distribution networks are quite common in supply chain and logistics. Deliveries of multiple items from factories to customers are managed by routing and consolidating shipments in depot carrying on long-term inventories. Hybrid strategies combining direct shipping, warehousing and cross-docking are usually applied in real-world distribution systems. This work deals with hybrid multi-echelon multi-item distribution networks. Lee, Jung, & Lee; Liao, Lin, & Shih; Wen, Larsen, Clausen, Cordeau, & Laporte, investigated different echelon strategies [77].

### 3. GREEN - VEHICLE ROUTING PROBLEM

The GVRP was mainly investigated since 2006. Green VRP is a special form of VRP with eco-friendly strategies. In Choy et al., the authors surveyed the VRP variants studied up until then, and summarized the state-of-the-art Green VRP (G-VRP). Based on some classification schemes[96], GVRP categorized into three sub categories: Green-VRP (2007), Pollution Routing Problem (2007) and VRP in Reverse Logistics (2006).

![Fig.2 Landscape of VRP][96]
Green-VRP (2007) - Green-VRP deals with the optimization of energy consumption of transportation. In G-VRP, many studies proposed eco-friendly strategies or algorithms by calculating vehicular fuel consumption [97]. With respect to methods for fuel consumption; Demir et al. not only summarized calculation methodologies, but also reclassified G-VRP based on the estimation method for it [78]. Their work described the big stream of the G-VRP area. The research on VRP in considering environmental issues such as fuel consumption or greenhouse gases (GHGs) was studied in the early 2000s. The overuses of energy and air pollution have imposed a threat on our ecological environment. Governments, non-profit organizations, as well as private companies have started to take the initiative to participate in this green campaign, they have made some energy policies for reducing fossil fuel consumption and for supporting alternative fuel, though barriers to implementing these sustainable solutions still exist. Researchers and entrepreneurs tend to pay close attention to the role that transportation will play in achieving positive environmental effects. The new green transportation solution may clash with the designated economic objectives. Exploring the relationship between environmental effect and transportation through route planning will be able to provide practical and valuable suggestions regarding this green campaign.

Pollution Routing Problem (2007) - The Pollution Routing Problem (PRP) aims at choosing a vehicle dispatching scheme with less pollution specially reduction of CO₂, Green House Gas. The road transport sector accounts for a large percentage of these emissions and has direct or indirect hazardous effects on humans and on the whole ecosystem [98]. PRP not just accounts the travel distance, but also for the amount of greenhouse emissions, fuel, travel times and their costs [79]. Mathematical models are described for the PRP with or without time windows and computational experiments are performed on realistic instances. Freight transport in the United Kingdom is responsible for 21% of the CO₂ emissions from the transport sector, amounting to 33.7 million tonnes, or 6% of the CO₂ emissions in the country, of which road transport accounts for a proportion of 92%. Similar figures apply to the United States, where the percentage of total GHG emissions from transportation rose from 24.9% to 27.3% between 1990 and 2005, with road transport accounting for 78% of the emissions produced by all transportation modes [80].

VRP in Reverse Logistics (2006) - In today’s competitive environment, green logistics issues a regaining interest. Reverse Logistics can be defined as "The process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal". VRP in Reverse Logistics (VRPRL) focuses on the distribution aspects of reverse logistics. In 2007, Srivastava, considered green logistics as a relevant social and economical issue [81]. Sub-divided into four categories:

Selective Pickups with Pricing- Only choose profitable pickup points to visit and make the collection operation as profitable as possible.

Waste Collection- Waste management, including waste avoidance, reuse and recycling, is a key process in protecting the environment and conserving resources.

End-of-life Goods Collection- The collection of some components of end-of-life products can benefit the original manufacturer because the recycled materials or components remain functional after further disposal or remanufacturing.

Simultaneous Distribution and Collection- Simultaneously Deliver and pickup to formulate the distribution process of reverse logistics.

4. Scope On GVRP

VRP aims to find a set of routes of minimum length (or travel time) for a fleet of vehicles initially located at a distribution center. In 2006 -2007 constrains that demands of customers have to satisfy but the loading limitations of the vehicles must not exceed has been added [82,83]. In 2006, Ericsson et al. Identified the impact of traffic disturbance events on fuel consumption and proposed a model for estimating the potential reduction in fuel consumption through route optimization [84]. In 2008, Tavares et al. took into account the effect of both road inclination and vehicle load on fuel consumption in waste collection [85].

According to a report of US Department of Energy (2008)[86], several factors influence fuel economy:

Weight of load- An extra 100 lbs in a vehicle could increase fuel consumption by up to 2 per cent.
Speed of transportation- Gas consumption usually increases rapidly at speed above 60 miles per hour. Moreover, gas consumption on the highway is lower than in the city.

Use of air-conditioning- Using an air-conditioner can reduce miles per gallon (MPG) by up to 20 per cent.

Colour of vehicle- On a sunny day, the surface temperature of a dark colour vehicle is higher than a light colour vehicle by as much as 368°F. This would influence the use of air-conditioning and hence influence the MPG.

Inflation of tires- Keeping tires inflated to the proper pressure could improve gas mileage by around 3.3 per cent.

Use of baffle- Fitting a vehicle with a baffle can improve gas mileage by more than 6 per cent.

In 2010 Kuo and Wang divided the total routes in to a number of sub-sequences (or sub-routes). Starts and ends at the same distribution centre. The transportation speed is classified into three levels – high speed, medium speed and low speed.

High speed is assumed for transport on a highway,

Low speed is assumed for transport in the city,

and

Medium speed is between the other two transportation speeds.

Shortest distance search (SD) and least fuel consumption search (LF) are used to calculate the initial solution [87].

In 2012, Miller-Hooks; Xiao et al., etc Fuel cost accounts for a significant part of the total cost of the petroleum-based transportation. Reducing the fuel consumption and improving the transportation efficiency at an operational level would be the most straightforward course of action. It is also desirable that decrease petroleum-based fuel consumption can correspondingly reduce the greenhouse gas emission significantly [88].

In 2007, Kara, Kara, and Yetis considered a more realistic cost of transportation that is affected by the load of the vehicle as well as the distance of the arc travelled. They define Energy Minimizing Vehicle Routing Problem (EMVRP) as the CVRP with a new objective of cost. The cost function is a product of the total load and the length of the arc. They simplify the relationship between minimizing the consumed energy and the variables of the vehicle conditions [89].

The Parametric Analytical Model of Vehicle Energy Consumption, and the Comprehensive Modal Emission Model which have been used to test various strategies for CO2 reduction (e.g.,). However, from the perspective of minimizing pollution in transportation planning, not much has been done [90].

The PhD dissertation of Palmer (2007) presents an integrated routing and emissions model for freight vehicles and investigates the role of speed in reducing CO2 emissions under various congestion scenarios and time window settings [91]. The model uses a known VRPTW heuristic as a black-box solver to produce the routing plans within the model. One of the main results is that savings up to 5% in CO2 emissions can be achieved over time minimizing plans. Palmer does not, however, account for vehicle loads in his model, although this is offered as a future research topic [91]. Maden et al. consider a vehicle routing and scheduling problem with time windows in which speed depends on the time of travel [92]. The authors describe a heuristic algorithm to solve the problem and report up to 7% savings in CO2 emissions by solving a case study involving scheduling of a fleet of delivery vehicles in the United Kingdom. In 2012, Xiao et al. proposed a Fuel Consumption Rate (FCR) considered CVRP (FCVRP), which extends CVRP with the objective of minimizing fuel consumption. In their paper, both the distance travelled and the loads are considered as the factors which determine the fuel costs. FCR is taken as a load dependent function, where FCR is linearly associated with the vehicle’s load [87].

Demir et al. not only summarized calculation methodologies [78], but also reclassified G-VRP based on the estimation method for it (Figure 3, Table 1). Their work described the big stream of the G-VRP area and addressed the current status of the research in this area.

Fig.3 The diagram of fuel consumption models [78]

<table>
<thead>
<tr>
<th>Fuel consumption model</th>
<th>Description</th>
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<tbody>
<tr>
<td>MEET</td>
<td>Methodology for calculating transportation emissions and energy consumption</td>
</tr>
<tr>
<td>NTM</td>
<td>Network for transport and environment</td>
</tr>
<tr>
<td>COPERT</td>
<td>Computer program to calculate emissions from road transportation</td>
</tr>
<tr>
<td>ECOTRANSIT</td>
<td>Ecological transport information system</td>
</tr>
<tr>
<td>NAIE</td>
<td>National atmosphere emissions inventory</td>
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<tr>
<td>NOX</td>
<td>Mobile vehicle emission factor model</td>
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<tr>
<td>MOBLE</td>
<td>Motor vehicle emission inventory</td>
</tr>
<tr>
<td>MOVES</td>
<td>Handbook emission factors for road transport</td>
</tr>
<tr>
<td>GREET</td>
<td>Greenhouse gas, regulated emissions, and energy use in transportation</td>
</tr>
<tr>
<td>EME</td>
<td>Lifecycle emissions model</td>
</tr>
<tr>
<td>PHEM</td>
<td>International vehicle emissions model</td>
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<tr>
<td>EMFAC</td>
<td>Emission factors model</td>
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<td>IFCM</td>
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<td>VTMicro</td>
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<td>PERE</td>
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<td>CFPMs</td>
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<td>CMIF</td>
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Table 1: Acronyms for fuel consumption models

Most of G-VRP studies took travel time and weights of vehicles into consideration as key factors for CO2 emissions.
In 2010, Maden et al. emphasized the importance of planning the vehicle routes considering time-varying data, and demonstrated the approach could also lead to CO₂ reduction [92]. In 2010, Kuo put the time-dependent speed into the TDVRP while accounting for minimal CO₂ emissions [93]. In 2010, Finglizzi suggested Emissions VRP (EVRP) which considers time-dependent travel speeds, time window and the vehicle’s capacity, and proposed that relaxing the time window slightly could lead to more reduction of CO₂ emissions [94]. In 2011, Bektas and Laporte developed Pollution Routing Problem (PRP) as an extended version of VRPTW, which has the objective function that combines the cost of CO₂ emission and the wages of drivers [80]. The graph of their equation is shown in Figure 5:

![Graph showing fuel consumption as a function of speed](image)

**Fig.5 Fuel Consumption As A Function Of Speed [80]**

In 2012, Li contributed to the fact that vehicle routes constructed to minimize distance can be better than ones minimizing travel time in CO₂ reduction [71]. As well, in comparison with the minimal-distance and minimal-time solutions, the minimal-fuel solution had strength in CO₂ emissions, especially when the problem size increased. Another problem of G-VRP deals with the recharging or refuelling of the vehicles. Papers concerning fuel consumption merely come up with the formulation for computing the fuel consumption, assuming that the fuel is adequate for covering the whole tour. They do not consider the distance limitation that depends on fuel tank capacity. In 2012, Erdöl and Miller-Hooks is the first to consider the possibility of recharging or refuelling a vehicle on the route in VRP [88]. In this concept, Vehicles are allowed to refuel on the tour to extend the distance it can travel. With the objective of minimizing the total distance, the model seeks to eliminate the risk of running out of fuel. They consider service time of each customer and the maximum duration restriction was posed on each route. In the same year, Schneider, Stenger, and Goeke D. extended GVRP with time windows [95].

### III. Conclusion And Future Research Prospects

Since road transport is a major contributor to CO₂ emission, there have been many works designing environmentally friendly vehicle routes in recent years. An eco-friendly vehicle route is dependent on what factors (e.g., vehicle weight, travel time and distance) are considered, and many researches shed light on the relationship between fuel consumption and these factors. The number of the publication on GVRP is growing, but they are still limited. Not only the numbers of meta-heuristics which have been used are limited, but also there may be better solutions through other meta-heuristics. More studies for exact methods for CO₂ reduction need to be researched. The cost of CO₂ emissions does not seem to be as important as fuel or labour costs. However, we need a useful tool to evaluate the impact of energy reduction incentives, such as carbon taxes. To test any model incorporating energy use and environmental impact, public policy, engineering, transportation system management, and even urban planning is needed. The wide scope of the research content requires an interdisciplinary and systematic approach provided by researchers and engineers from different backgrounds like govt. The time windows and the customer demand in place will make more room for the reduction of energy consumption. Queuing models and inventory models might be involved in this problem to make the studies more convincing. Using the fuzzy theory, future studies may explore the trade-off between customer satisfaction, environmental cost and economic cost.

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