Electric commercial vehicles: Practical perspectives and future research directions

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A B S T R A C T
The existence of an efficient, sustainable and environmentally friendly “green” freight transport system requires several challenges to be addressed to reduce negative externalities. Over the last few years, the efforts for technological improvements and innovation in transport have been intensified and fleets of vehicles using renewable sources is the new trend for public authorities, non-profit organizations and many private companies promoting sustainable development. This paper studies the use of electric commercial vehicles within the spectrum of “green” transport, provides a critique of their key technical specifications and identifies the main operating conditions that influence their effectiveness. It is an attempt to exploit challenges and contemplate policy adjustments for the wider take-up of electric commercial vehicles in daily transport operations within the EU area.

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1. Competitiveness of electric vehicles

Increasing globalization and competition in most sectors further enhances the importance of a sustainable and energy-efficient “green” freight transport system that can lead to both economic and environmental improvements. Freight transport activities are responsible for the consumption of a large percentage of oil reserves worldwide over the last decades, a trend which is expected to increase the coming years. In EU, the predictions show a significant increase in the total freight transport activity by about 57% within forty years (2010–2050) and the transport sector is expected to be the largest source of CO2 emissions according to the POLIS network of European cities and regions. EU has announced an energy roadmap (European Commission, 2012), which aims to reduce emissions by 20%, increase the share of renewable energy to 20% and achieve 20% energy efficiency improvement by 2020. Road freight transport contributes to 33% of total transport emissions (Faberi, Paolucci, Lapillonne, & Pollier, 2015) including city logistics. EU policies have been developed to support deployment of new sustainable fuels and propulsion systems aiming to boost the penetration of Electric Vehicles (EVs) and achieve CO2 reductions from light commercial vehicles.

During the last decade, EVs are being perceived by Japan, European and North-American countries as well as by emerging economies – China and India – as a promising solution for their urban freight distribution. In 2009, the US Department of Energy granted $2.4 billion in order to support innovation and production of the next generation of US batteries and EVs (The White House, 2009). Furthermore, Courier, Express and Parcel, and pharmaceutics services have already included EVs in their fleet to serve regionally limited areas reducing noise, air pollution and GHG emissions. However, practical deployment of EVs in Europe still requires substantial effort to accelerate the development of cost-effective solutions and achieve bigger impact from scarce public and private resources (Electromobility+, 2014).

The use of EVs has become a crucial concern for public authorities and modern companies seeking to reduce their environmental footprint and their operational costs. In conjunction with GPS trucking services, an effective decision making for using EVs could be achieved providing reliability and wider acceptance. In the context of effective decision making, the Electric Vehicle Routing Problem (EVRP) has been developed to capture the operating conditions, embodying multiple constraints enforced in practice for urban freight distribution using EVs. Although the utilization of EVs follows an accelerated pace, the literature about effective solution approaches for electric vehicle routing and scheduling is limited and there is significant need for further research. According to the studies of Feng and Figliozzi (2013) and Davis and Figliozzi (2012), route feasibility, minimum fleet size, minimum travelled distance, charging level, purchase costs and planning horizon are critical parameters for the assessment of the EVs utilization, while
the overall key aspect for the EVs’ success depends on the operational cost savings that should be significantly high to overcome the initial purchase costs.

This paper aims to identify the key technical specifications of EVs and the main operating conditions that influence their effectiveness based on previous experience and review of literature and success stories. A critique of the abovementioned issues is provided, followed by a discussion on practical applications, challenges and policy recommendations for the wider take-up of electric commercial vehicles in transport operations. The added value of this paper is to link theory and practice providing the basis for future research about EVs utilization. Outcomes could be used to support both public and private sector stakeholders seeking to rationalize and improve the efficiency of transport promoting the use of EVs.

The remainder of the paper is organized as follows: The “Technical specifications” section provides an overview of the EVs market mainly concerning batteries and charging methods, “Practical applications” section describes success stories of EVs’ utilization in European cities and “Operating conditions” section presents the definition of the problem with regard to energy and operational cost optimization. Finally, the section “Challenges and Recommendations” addresses the problems and the potential research areas that might be studied in the future as well as policy recommendations that can lead to a rapid and more effective implementation of EVs.

2. Technical specifications of EVs

2.1. EV chassis types

Studying the European market of freight/commercial EVs, it is observed that they are similar to the conventional vehicles in terms of body style despite their special features (i.e. the use of light weight chassis material and battery pack compartment) since manufacturers utilize their existing models for their development in an effort to minimize the production costs. EVs can be classified according to their gross weight and are distinguished to four main categories in a corresponding way as conventional goods vehicles. This classification is provided below:

(i) “mini vans” of a max 550–650 kg payload with gross weight < 2.5 t (i.e. Renault Kangoo Z.E., Peugeot Partner electric, Nissan eNV200, Ford Transit Connect)
(ii) “vans” of a max payload of about 1000 kg with gross weight < 3.5 t (i.e. Mercedes Sprinter)
(iii) “trucks of 1100–3500 kg payload with gross weight < 7.5 t” (i.e. Smith Edison)
(iv) “heavy trucks” of more than 3500 kg payload with gross weight > 7.5 t” (i.e. Smith Newton, EMoss, Terberg)

The gross weight of a vehicle is the weight of the empty vehicle plus the weight of the maximum payload that the vehicle is designed to carry. Based on the general manufacturers’ specifications, the difference between the empty weight of the vehicle and the gross weight varies among small light and larger vehicles. The difference for small light vehicles is only about 250 kg while the payload capacity share of medium-sized vehicles is between 50% and 100%, and for the largest vehicles it reaches 200%. Considering also that the vehicle weight affects medium-sized vehicles is between 50% and 100%, and for the largest vehicles is only about 250 kg while the payload capacity share of the empty weight of the vehicle and the gross weight varies among the different models.

2.2. EV battery types

There are various battery types of EVs in the market and they differ in terms of capacity and amount of cells (Den Boer, Aarnink, Kleiner, & Pagenkopf, 2013). Table 1 presents the different types and provides information about their energy density and their expected cycle life. The most commonly used are the Lithium-ion batteries (AVERE, 2014), which offer much higher energy density than the other types. On the other hand, their performance may significantly decrease for temperatures lower than 10 °C or higher than 45 °C (Zhang, Kong, Li, & Li, 2014). The latter indicates that temperature affects the way an EV operates and thus, weather conditions belong to the critical parameters that should be considered for EVs utilization in the context of “green” transport.

2.3. EV range

EV range is a broadly discussed factor, which depends on the energy losses and is affected by the following parameters (Bingham, Walsh, & Carroll, 2012; Duarte, Varella, Gonçalves, & Farias, 2014):

(i) Design parameters such as vehicle weight and size (drag from the air over the body of the car and through the front radiator)
(ii) Drivetrain characteristics (inverter, motor, gearbox, bearings)
(iii) Vehicle ancillaries (12 V loads, cooling fans and pumps, lights, etc.)
(iv) Battery characteristics (capacity and load)
(v) Battery age (age degradation and Depth of Discharge, number of cycles)
(vi) Weather conditions (extreme cold or hot)
(vii) Routing parameters (road inclinations, vehicle speed)
(viii) Driving style (excessive speeding, hard acceleration and non-progressive deceleration)

The range for EVs (according to the manufacturers’ specifications) is about 100 km and real life applications reveal that in an urban environment the average daily driving distance is not larger than 100–150 km (E-Mobility NSR, 2013).

2.4. Plug-in vehicle charging

The most common technique used for EVs charging is the plug-in method, while inductive charging methods (stationary and dynamic) are at a more experimental stage even though they are also commercially available.

Connection between the vehicle and the Electric Vehicle Supply Equipment (EVSE) is achieved through the use of a specially designed connector (plug) that is then connected to a vehicle inlet (socket). Three official types of connectors are available in the market, with automakers taking a less standardized approach based on the continent of origin. Type 1 (Yazaki or SAE J1772) is predominantly used in the U.S., Japan and some European automanufacturers. This type of connector

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<td><strong>EV batteries</strong></td>
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<tr>
<td>Nickel Cadmium (Ni–Cd)</td>
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<td>Nickel Metal Hydride (Ni–MH)</td>
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<td>Nickel Zinc (Ni–Zn)</td>
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<td>Sodium/nickel chloride (Zebra)</td>
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is capable of only 1-Phase AC current charging at 32 A and 250 V (Laarakkers, Celaschi, & Gonzalez, 2012). Type 2 (Mennekes or IEC 62196-2 Type 2) is a connector mainly adapted by the EU auto manufacturers and is capable of either 1-Phase or 3-Phase charging at 70 A or 63 A respectively and up to 500 V (Laarakkers et al., 2012). The most rare connector type mainly used in Italy or France is the Type 3 (Scame), with the same capabilities as Type 2 but with different geometry. Apart from the abovementioned types, two more DC fast/rapid charging connectors exist. CHAdeMO is the most popular connector (offered by Japanese and some European automakers) for rapid DC charging and offers 125 A at 500 V. In general, the type of connector used for charging EVs is the most crucial part that affects compatibility with the available charging network infrastructure as well as charging time (due to the capabilities of the EVSE attached to it). The type of connectors varies between EVs and depends on the country of origin of the automaker. Studying the EVs global market, it is observed that the American freight EVs use Type 1 connectors while the European use Type 2. The latter indicates that a large number of EVs are not able yet to accept Mode 4 DC rapid charging that takes 20–30 min for fast recharging up to 80% enhancing their use in urban freight distribution activities. In Europe, COMBO 2 (IEC 62196-3 Type 2 Combined Charging System (CCS) Combo 2 Connector) is the most common rapid charging solution for passenger vehicles that deals with this problem and is supported by German automakers.

2.5. Battery swapping

The case of battery swapping – as an alternative to plug-in charging – has been introduced by Better Place Corporation. The company offered the choice of leasing both EV battery packs and plug-in charging. The idea was to install service stations where the customers could swap their batteries only within 3–5 min using an automated system (Christensen, Wells, & Cipcigan, 2012). The same idea of battery swapping has been also carried out by GreenWay Company by converting diesel Citroen Jumper vans to electric and creating a network of service stations where battery swapping could take place. In this case the battery swapping is not automated, but instead it is carried out by the driver within 5–7 min using a manual electric forklift (Greenway, 2014). The empty battery is taken out of the van and swapped with a fully charged one that is removed from a storage unit. Although it does not offer an automated service, the GreenWay attempt of swapping station appears competitive since it is much less capital intensive. In practice, the GreenWay modified vans have already been used effectively for pharmaceuticals and medical material distribution in the Slovakia region. Even though the GreenWay concept seems as an efficient method for having a fully charged battery pack within a couple of minutes, it requires user’s familiarization with the operation of a forklift and with the storage of dangerous loads. It actually demands from the vehicle operator a hands-on mentality that might not be appealing to vehicle drivers and fleet managers at the moment.

2.6. Concise critique

Environmental impacts and the relevant predictions about increased GHG emissions have imposed the development of proper measures for an energy-efficient “green” freight transport system. Towards this direction, EVs utilization could be the basis for “green” city logistics. Despite the expensive replacement of a battery pack in case of a failure, the maintenance costs are 20–30% lower than those of conventional vehicles (AVERE, 2014; Feng & Filigozzi, 2013) mainly due to the simplicity of an electric motor (less moving-rotating parts). Companies like Fed Ex and PG&E have verified this finding by reporting lower maintenance costs (Electrification Coalition, 2012a, 2012b) after utilizing EVs for their daily operations. Moreover, since delivery vehicles tend to follow the same route each day and return to the company premises every night, the possibility to recharge slowly during the night is a satisfying solution that could be implemented for urban distribution activities. This is further supported by Nesterova et al. (AVERE, 2014) and E-Mobility NSR (2013), which indicated that the charging of EVs could take place during the night while the vehicle is parked at the depot. A very commonly proposed charging scheme is for the vehicle to be fully charged overnight with several short charging sessions during the day either during lunch breaks or between jobs since charging time has been reported to be between 4 and 8 h for full battery charging with a possible 45 min for battery charging up to 80% (AVERE, 2014).

On the other hand, fleet operators and interested stakeholders need to consider that EVs utilization requires specialized personnel for EVs maintenance and trained drivers that obey speed limits imposed by manufactures for efficient energy consumption (AVERE, 2014).

3. Practical applications

With the aim to enhance a “green” transport system adopting more energy-efficient measures for their daily logistics operations, both private corporations and public authorities have already added EVs to their fleets. Energy-efficient and environmentally friendly logistics solutions translate into cleaner vehicles on the road today and more efficient vehicles in the years to come. Previous experience from the European Association for Battery, Hybrid and Fuel Cell Electric Vehicles (AVERE, 2014) regarding successful EVs implementation and the main outcomes from the E-Mobility NSR EU-funded project aimed to support the wider use of electric mobility in EU countries, and identified the operational and territorial conditions that render the EVs utilization successful. Specifically, EVs tend to become essential in urban and peri-urban logistics operations where the technical characteristics of the EVs appeared as their competitive advantage. The high constant torque of the EVs at all speeds, their energy efficiency in heavy traffic, their manoeuvrability in narrow streets as well as their noise and air emissions free operation stimulate their use in urban freight distribution promoting better accessibility and cleaner cities in terms of GHG emissions. In this context, Table 2 summarises real-life applications of EVs for various logistics operations providing a brief description of their nature as well as the financial and regulatory initiatives.

The EVs could also be used by other industries that appear with similar nature of their daily operations. First of all, the utilization of EVs could be effective in manufacturing industry since it requires sufficient carrying capacity as the “Delivery and collection of hire equipment in urban areas” category does. In practice, BMW uses a 40 t truck in transporting parts from the logistics centre to one of their manufacturing plants in Munich (Robins, 2015). Similarly, catering industry could be a promising sector since food should be transported to customers where vehicles can be charged (if it is required) while the events take place. Two specialized industries that belong to the “Logistics services of various goods and parcels” category is the transportation of pharmaceutical and retail distribution within the urban areas. Additionally, fast food deliveries could be a potential market for smaller or purpose built EVs, where their size and energy efficiency can become a key element of success. However, mixed fleets is the most common approach appearing in real-life since EVs still constitute a niche market. Based on their technical specifications (as described in Section 2) their use should be promoted for urban and peri-urban areas where there are short distance tours and emissions mitigation is critical. On the other hand, conventional vehicles should be preferred for servicing distant locations and tours in the national road network.

4. Operating conditions

In an attempt to promote wider acceptance of EVs for “green” urban distribution, energy efficient decisions about daily operations constitute a major requirement by interested stakeholders from both private and public sector. As already mentioned, the energy consumption rate varies between plug-in and battery EVs and also, affects the daily routing and
scheduling decisions since extra computational effort and time is required for their recharging or battery swapping processes. For this reason, we review the main studies that motivate the research in the field of EVs routing and scheduling optimization based on the charging technique used.

### 4.1. Battery swapping vehicle routing and scheduling optimization

There are only few studies focusing on battery swapping EVs routing and scheduling optimization and this sparse research interest originates from their market share, which is still very low. Mak, Kong, and Shen (2013) studied the Battery Swapping Station (BSS) location problem and the potential impacts of battery EVs development and their infrastructure deployment proposing two robust optimization models for the BSS problem. More recently, Goeke and Schneider (2014) developed an Adaptive Variable Neighbourhood Search (AVNS) algorithm to deal with the BSS problem and the capacitated EVs Location Routing Problem (EV-LRP) minimizing the sum of construction and routing cost. Furthermore, the reported results on benchmark instances of the related problem Electric VRP with Time Windows restrictions (EVRTW) prove the high performance of their proposed solution approach.

Finally, Yang and Sun (2015) present a four-phase heuristic and a two-phase Tabu Search (TS) to deal with both the BSS and the EV-LRP. In addition, an economic and an environmental analysis conducted providing information about the battery driving range and the emissions’ reductions achieved using EVs for logistics operations.

### 4.2. Recharging vehicle routing and scheduling optimization

In terms of VRP with recharging EVs objectives, two main classes can be distinguished. The first class refers to the energy cost while the second class, that attracted the main interest of the research society, is oriented to the operational cost which includes the acquisition costs and the travel costs for the total number of vehicles following the original notion of the VRP. A more detailed description of this classification and its limitations are provided in the following paragraphs.

#### 4.2.1. Energy cost optimization

This class covers problems where the main objective is to minimize the energy consumption promoting sustainability. In the literature, this objective has been first referred to in the study by Barco, Guerra, Muñoz, and Quijano (2013) dealing with the Electric VRP (EVRP) from the...
public transportation perspective presenting a case study about carrying passengers from an airport to a hotel using EV. A solution framework that coordinates the routing, charge scheduling and operating costs is proposed taking into account the battery degradation as well as the recharging cost, while patterns allowing the increase in the battery lifetime were also obtained. Additionally, in Bouache, Trigui, El Faouzi, and Billot (2013) efficient tools are presented to minimize the energy consumption using dynamic speed data and travel time information following the Shortest Path Problem (SPP) notation. A similar objective appeared in Artmeier et al. (2010) that study the Constrained Shortest Path (CSP) in an effort to obtain the energy-optimal route from a predefined origin to a destination. Finally, a study by Felippe, Ortuño, Righini, and Tirado (2014) deals with a modification of the EVRP, which allows partial recharges within the service and aims to minimize the total recharging costs considering the recharging cost at the depot before service starts, the recharging costs at the stations during the service and the fixed costs associated with the battery cycles. The proposed solution method is based on the special characteristics of the problem and utilizes a Simulated Annealing method following a deterministic construction heuristic and an improvement local search algorithm.

4.2.2. Operational cost optimization

This class refers to problems where the main objective is to minimize the travel cost in terms of total distance travelled, total travel time or other relevant costs. Conrad and Figliozzi (2011) present a study in freight deliveries and examine the Electric Vehicle Routing Problem with Time Windows (EVRPTW) where vehicles are recharged at customer locations during the service process. A regression analysis is implemented for the estimation of the average distance travelled at customer locations during the service process. A more generic study conducted by Erdogan and Miller-Hooks (2012) for the Green Vehicle Routing Problem (GVRP) encompasses the challenges associated with alternative fuel vehicles as the EVs. They initialized the use of heuristic solution methods developing a modified Clarke and Wright (1964) as well as a density-based clustering algorithm followed by a customized improvement technique that utilizes an inter- and intra-route exchange neighbourhood search.

Pourazarm and Cassandras (2014) deal with the EVP with inhomogeneous recharging stations considering traffic congestion and waiting time for recharging, and study the effect of two different scenarios: (i) a single vehicle routing problem and (ii) a multiple vehicle routing problem with the objective to minimize the total elapsed time. A mixed-integer nonlinear programming is used for the single-vehicle case and a Linear Programming formulation is developed to obtain high quality solutions for the second case. Similarly, Schneider, Stenger, and Goek (2014), study an EVP with intermediate recharging stations. The suggested hybrid metaheuristic framework incorporates a Variable Neighborhood Search algorithm and a Tabu Search algorithm in order to improve the initial routes gained following a myopic heuristic procedure. It is the first attempt to develop a robust and sophisticated solution approach that incorporates efficient search mechanisms in order to enhance accuracy, speed and flexibility. In an effort to exploit the scientific background, Schneider et al. (2014) used the data sets generated by Erdogan and Miller-Hooks (2012) and obtained new best known solutions. Furthermore, their work constitutes the basis for future research and systematic analysis of the EVRPW since they provide benchmark data sets for both small and large scale instances.

The EVRPW is further studied by Keskin and Catay (2014) with the aim to minimize the total distance travelled, and an Adaptive Large Neighborhood Search (ALNS) algorithm is developed utilizing several removal and insertion mechanisms dynamically according to their performance. Hiermann, Puchinger, and Hartl (2014) also propose an ALNS method to deal with a generalized mixed vehicle routing problem which encompasses the well-known Fleet Size Mix Vehicle Routing Problem with Time Windows — FSMVRPTW (Bräysy, Dullaert, Hasle, Mester, & Gendreau, 2008) and the EVRPW. Additionally, Desaulniers, Errico, Irnich, and Schneider (2014) study four recharge alternatives (1. single and partial recharge, 2. single and full recharge, 3. multiple and partial recharges, 4. multiple and full recharges) for the EVRPW and an exact branch-price-and-cut algorithm is presented to generate feasible solutions for each variant of the problem.

Inspired by the practice, Goekke and Schneider (2014) study the VRP with time windows utilizing both conventional and electric vehicles and an ALNS algorithm developed to address this problem. They introduced a realistic energy consumption model based on critical factors (i.e. speed, gradient and load) for the first time in the literature, in an attempt to determine the driving range of the EVs and the recharging waiting time at the stations. Finally, Bruglieri, Pezzella, Pisacane, and Suraci (2015) designed a Variable Neighborhood Search Branching (VNSB) for solving the EVRPW within reasonable computational time limits. In an effort to capture the real — life routing and scheduling decisions using EVs, recharging processes are studied and the relevant restrictions are considered.

4.3. Concise critique

Over the past years quite a few research studies have been dedicated to model aspects and develop solution methods in the field of EV routing and scheduling optimization since the use of alternative fuel vehicles emerged and EVs have already surpassed our expectations to progress and innovation as already presented. Due to the accelerated pace of the EV penetration in urban deliveries, freight distribution has received researchers’ attention resulting in several efficient solution approaches and important advances. However, this research interest has led to confusing modifications of well-known optimization problems, such as the VRP (Toth & Vigo, 2002), presenting different objective functions and operational constraints in order to capture the special characteristics of the EVs and their sensitive restrictions. Indeed, the comparisons among different proposed solution approaches are not always feasible even though there are several studies regarding the use of EV in distribution activities. This impedes the research progress as well as the commercially practical recommendations and developments.

Overall, the general characteristics of the optimization problems appeared in the literature as well as the corresponding goals and objectives are depicted in Table 3. Due to the nature of transportation services, objectives for a sustainable transportation system could be also conflicting especially in cases that both operational and environmental costs should be improved. Moreover, optimizing both energy and operational objectives presents high computational complexity and corresponding studies are still not available, indicating a pointer for future research.

5. Challenges and recommendations

This paper draws essential observations about the recent trends of the EVs in urban freight transport services and analyses technical specifications as well as operational issues for routing and scheduling procedures. Since conventional freight vehicles are still widely implemented and the technological shift towards alternative sources of energy as well as the developments in transportation sector has resulted to different types of freight vehicles with particular specifications offering a wide variety of design opportunities and expectations. Hence, managing various types of vehicles can be complicated and time consuming increasing the operational costs.

Modern composite materials for the chassis of the EVs could reduce the weight without any compromise to crash safety and vehicle stability. Loss of weight is actually a manufacturing target in order for the vehicle to maintain its crash compatibility among other advantages such as lower rolling resistance, brake power and energy saving. Moreover, the production of EVs modular concepts on a cabin-chassis design for a city vehicle of max 7.5 t gross weight is a current need of the industry in order to deliver different goods to customers. This could achieve
reductions to the production costs and consequently to make more attractive the EVs to fleet operators that will own a multi-purpose fleet. It is not in the scope of this paper to deepen into technical aspects that are currently addressed by several research projects. However, running studies and practice showed that the range limitation of electric commercial vehicles in a critical issue. Material technology research is intensively undergoing focusing on electrode and electrolyte materials, with separators coming third as priority. New electrode concepts include many types of graphene, carbon nanotubes, nano-onions, aerogels and chemically-derived carbons. Future electrolyte needs are neutral aqueous electrolytes permitting low cost current collectors with higher voltage. Moreover, new ionic liquids for low temperature and new organic solvents, which are less toxic and non-flammable, have been identified as important topics for further research.

Super or ultra-capacitor batteries have also been introduced to EVs as an energy feeder to EV systems with the aim to last much longer. The most important issues that should be improved are the super capacitors’ low specific energy and the large possible voltage dispersion between individual cells in order to replace traction batteries in the future. Additionally, they could replace inverter capacitors supporting regenerative braking backup and automatic door/ramp opening processes.

The process of recharging EVs is an important issue as it greatly determines their use, both in terms of availability and flexibility. Regarding freight transport the recharging techniques that get most attention so far are slow charging, fast charging and battery swap stations. There is a critical problem due to the lack of compatibility of different charger plugs and thus, standardization of charging plugs on a worldwide level should be further discussed. Furthermore, a systematic energy management will contribute to the range extension without sacrificing comfort in all weather conditions (either winter heating or air conditioning). Towards this direction, the answer is a bunch of actions: a comprehensive thermal management system (including innovative heating and cooling, thermal insulation), energy efficiency of electrified accessories, electronic control of energy and power flows, energy harvesting functions and eco-driving strategies (European Commission, 2014). As far as the eco-driving is concerned, national authorities should encourage the development and future implementation of training schemes for the operation of electric vehicles to the professional drivers since their education proved to be as effective as novel technological advances.

Regarding the operational dimension, the appeared studies in literature deal with variant modifications of the classic VRP. Differentiated objectives are considered subjected to several operational constraints such that customer time windows, capacity limitations and energy consumption restrictions. The proposed solution schemes and the developed optimization algorithms seem to be at a very early stage without exploiting the scientific background of the methods introduced for a fleet of conventional vehicles. Only few sophisticated solution procedures, that embody approximation algorithms, memory structures, operators and efficient search mechanisms of the solution space, have been developed and this constitutes a research gap of not yet investigated optimization methods that could minimize the complexity of EVs routing and scheduling decisions.

Real-time information about travel times and customer requests could take the research a step further in an effort to capture the dynamic nature of real world problems. Another critical research direction is the study of the cooling/heating usage for the freight EVs and different scenarios (standard, cold and hot weather conditions) are necessary since the heating usage appears as a higher impact on energy consumption compared to the cooling. Heterogeneous fleet of vehicles, mixed fleet (conventional and electric), combined pickups and deliveries that increase synergies, as well as the case that customers own their charging infrastructure that allows fast recharging, are modifications that still are not explored and their accommodation in routing and scheduling models is a valuable pointer to future research.

Moving towards real life problems, empirical case studies are of great interest and input by practitioners render considerable efficiency to the research progress for addressing “green” transport services. There is a recent study in literature and some electronic platforms available in the market to support fleet management aiming to achieve monitoring, tracking, fuel management and other relevant services facilitating both conventional and electric vehicles utilization.

Therefore, novel policies and measures are required to meet the objective of deploying EVs in transport services across Europe. Based on the information provided by several EU funded research projects, the most common government regulatory measures should focus on multiple aspects such as providing financial incentives (i.e. subsidies and exceptions from purchase VAT), developing charging stations and imposing restrictive rules for conventional vehicles (i.e. restricted access and parking to the city centre, and toll roads). In addition, a wider take-up of EVs requires novel solutions to reduce their high initial cost and thus, battery leasing is reported as the most promising one.

Regarding the financial sources, government has to establish a strong collaboration with the industry in an attempt to achieve significant savings and fewer risks providing easier development and successful implementation. Aggregating funds could be used from multiple sources.
(such that credit assistance, taxes, fees, sponsors, funding programmes etc.) and a sustainable framework should be followed to plan, implement and evaluate their use in terms of both operational and environmental costs.

Transparency document

The Transparency document associated with this article can be found, in online version.

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