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Determining optimal deployment of electric vehicles charging stations: Case of Tunis City, Tunisia

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ABSTRACT

Due to their reduced fossil fuel consumption and transportation-related emissions, Electric Vehicles (EV) are increasingly emerging. Nevertheless, one of the most important decisions for EV adoption is the planning of EV charging infrastructure. In this work, we address the real case of the centre of Tunis City, Tunisia, where potential charging stations could be located in parking and gas stations. The objective is to place and size EV charging stations in such a way that EV drivers can have access to chargers, within an acceptable driving range, while real world life constraints are respected. We also consider investment costs, as well as EV users' convenience. Toward this end, five Integer Linear Programs based on weighted set covering models are proposed and solved to optimality. Computational experimentation provides optimal infrastructure schemes that public makers could adopt within the emerging environmental policy.

1. Introduction

Reliance on fossil fuels has negative effects on the ecological and economic environment. Public awareness is rising concerning environmental and ecological issues. One major way to reduce fossil fuel consumption is using Electric Vehicles (EV). Besides, the fact that EV market is increasing (OECD/IEA, 2016) is in line with consumers tending to switch to electric vehicles, if some adoption obstacles are leveraged (e.g. Chachdi et al., 2017; Juan et al., 2016). In addition to the high price barrier, electric vehicles still have a relatively short driving range. Therefore, the deployment of a charging network to improve users' charging access is crucial to encouraging the adoption of this ecological solution. Recently, some studies on deployment of Electric Vehicles Charging Stations (EVCS) were carried out in cities such as Seattle (Chen et al., 2013), Beijing (Zhu et al., 2016), Ankara (Erbaş et al., 2018), Istanbul (Genevois and Kocaman 2018), and Singapore (Wang et al., 2019). This exploratory work contributes to this emerging field by determining the optimal size, as well as the location, of EVCS within the city center of Tunis, Tunisia. It is worth mentioning that this a pioneer study in Tunisia, and probably in African countries, to the best of our knowledge.

1.1. Related work

Nowadays, EV charging devices are still under development and not yet fully standardised (Shareef et al., 2016). Nevertheless, and prompted by the rapid development of the charging technology, it is usually assumed that there are three types of charging terminals (also called chargers). The power of the so-called chargers Level 1, 2 and 3 ranges from 1.4 kw, 7.7 kw, and 13.3 kw to 1.9 kw, 25.6 kw, and 96 kw, respectively. Moreover, the average charging times of chargers Level 1, 2, and 3 are respectively 11.5 h, 2 h and 0.5 h. Thus, Level 1 charging is more suitable for home charging, while chargers of Level 2 and 3 are more suitable for public or private facilities. In line with many recent works (e.g. Çatay and Keskin 2017; Dascioglu and Tuzkaya, 2019), only Level 3 chargers are considered in this study. For an excellent survey on EV charging facilities, the reader is referred to (Baouche et al., 2014) and (Ghamami et al., 2016).

During the last decade, EVCS planning problems have been extensively investigated and are still catching the interest of both practitioners and researchers (e.g. Kumar et al., 2018). The interested reader is referred to the recent review papers (Islam et al., 2015), (Shareef et al., 2016), (Jing et al., 2016), and (Pagany et al., 2018). At this stage, it is worth noting that the problem of EVCS planning could be considered in relation to the city itself (Csiszár et al., 2019). On the one hand, because of the EV short range, there are the so-called *inter-city* EVCS location problems that usually focus on locating the stations on highway corridors (e.g. Sathaye and Kelley2013). On the other hand, the variant of *intra-city* or urban EVCS location problems is receiving

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increasing attention due to the fact that EV users are more often urban drivers (Giménez-Gaydou et al., 2016). In this case, the potential EVCS are usually available parking lots located within the urban area (e.g. Chen et al., 2013).

The existing literature about the EVCS planning covers a number of aspects. However, most relevant papers published so far focus on selecting sites for the EVCS. To solve this challenging problem, several modelling tools and solving approaches have been considered. Zhu et al. (2016) have proposed a genetic algorithm that minimises heuristically the sum of installation cost and EV users' travel costs of locating EVCS within a small metropolitan area in the city of Beijing. Similarly, Efthymiou et al. (2017) have developed a genetic algorithm, within the framework of an open-source user-friendly tool, devoted to finding appropriate EVCS deployment. Several mathematical models have also been investigated. Firstly, Frade et al. (2011) proposed a maximal covering location model for determining the optimal location of slow EVCS in Lisbon. Such a covering strategy was recently used by Mete et al. (2018) for finding optimal locations of bike-sharing stations within a university campus. Chen et al. (2013) have presented a Mixed Integer Linear Programming (MILP) formulation to find optimal assignment of EVCS to public parking locations within Seattle's downtown. The authors have also provided a predictive model to charging demand, based on parking demand data. Baouche et al. (2014) have addressed a fixed charge location Integer Linear Programming (ILP) model coupled with realistic p-dispersion constraints that minimizes the sum of the fixed EVCS installation cost and the EV user travel cost. Using a commercial solver, the model yields optimal locations for the EVCS within the city of Lyon, France. Recently, Li et al. (2018) reported a bi-level programming model that integrated decisions of both public makers and private owners of an EV fleet. A framework combining a variable neighbourhood descent based approach and a scatter search procedure is introduced to determine recharging infrastructures deployment. The performance of the proposed hybrid heuristic is assessed only on a dataset of benchmarks, without a real case study application.

In contrast to studies on EVCS location, the literature on both locating and sizing EVCS is relatively scant. For an urban zone of Tehran, Sadeghi-Barzani et al. (2014) constructed a Mixed Integer Non-Linear Programming (MINLP) model that aims to minimize the installation cost of EVCS, including land, investment and electrification costs, as well as the electric grid loss and the EV energy loss in transmission. A genetic algorithm is provided to find adequate fast charging station placing and sizing. Experimentation showed that the cost of installing the EVCS represents one of the main parts of the total costs. In the same vein, a realistic multi-objective optimisation problem is formulated by Mozafar et al. (2017) taking into consideration several minimisation objective functions, such as voltage fluctuations index, power losses, depreciation of EV battery value and EVCS installation costs. A genetic algorithm, coupled with a particle swarm optimization based procedure, is established to find the appropriate allocation of the EVCS, as well as the renewable energy sources. In an inter-city context, Wang et al. (2018) have recently proposed a hybrid genetic algorithm within a two-stage procedure to first sit and then size EVCS in a highway network. The EV drivers' charging strategy is formulated with utility theory principles, taking into account the congestion of the site of each charging station. It is worth mentioning that the proposed procedure contains optimization, mainly in the first stage of the EVCS site selection procedure.

With regard to theoretical works or real case studies, there are almost no research papers that focus on developing or African countries, to the best of our knowledge. Besides, the large majority of the studies above provide heuristic approaches and more precisely enhanced genetic algorithms. This exploratory work contributes to the emerging field of EVCS sitting and sizing by addressing an appropriately weighted set covering based models under real life constraints. Solved to optimality, the proposed models provide an optimal scheme for the EVCS location and sizing, within the city centre of Tunis, Tunisia.

1.2. Context and contributions

Being a signatory of the Paris Agreement, within the United Nations Framework Convention on Climate Change (UNFCCC, 2016), Tunisia has to take adequate measures to decrease greenhouse gas emissions, including the promotion of EV adoption. In this context, we are looking for optimal location, as well as sizing, EVCSs in one of the most densely-populated urban area of Tunisia: the centre of Tunis. To this end, we investigated several models regarding investment costs and users' convenience. To the best of our knowledge, this approach has only been addressed in a recent paper by Bouguerra and Layeb (2018), where the authors used two basic ILP models yielding only decisions about the location of the potential EV charging stations.

In this paper, we mainly make the following contributions:

We propose five ILP models to solve an urban parking EVCS location and sizing problem. These models are grouped into two families: (i) ILP models for location decisions only; and, (ii) ILP models for location and sizing decisions. Each of these families is characterised by specific decision variables, corresponding objective function, and appropriate real world constraints.

We present a real case study on the city centre of Tunis, Tunisia. For this pioneer work, a site investigation was conducted to collect and prepare data. The proposed infrastructure deployments would help Tunisian authorities to decide on locating future EVCS.

1.3. Paper structure

The remainder of this paper is organised as follows. Section 2 describes the case study and the proposed Integer Linear Programming models. Section 3 reports the numerical experimentation and the proposed infrastructure installation schemes. Finally, Section 4 draws conclusions and provides avenues for future research.

2. Problem modelling

2.1. Assumptions

For the sake of convenience, we have made the following key assumptions:

- only day time charging is considered for the EV users. This seems convenient for a workplace urban area, such as our case study;
- only fast chargers (Level 3) are considered, and each installed charger could serve more than one EV;
- -the access of EV drivers to a charging station within a tolerable travelled distance is a requirement;
- each EV can only be charged at one station.

2.2. Network preparation

An important phase of this study is identifying potential locations for future EVCS. As considered in previous works such as Chen et al. (2013) and Zhu et al. (2016), candidate locations for the EV charging stations are existing gas and parking stations in the area included in the study. Geographic data is collected from Google Maps@. Parking lot data is also gathered from the Tunis municipality website (http://www.commune-tunis.gov.tn). A field study was also conducted to consolidate all these data. Details on potential locations are given in Annex 1. As shown in Fig. 1, we identified *31* parking lots (marked in red) and *8* gas stations (marked in blue) within a *4.5* by *2.5 km* service area.

Once the 39 candidate locations candidates had been identified, a