Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective

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A B S T R A C T

The unprecedented growth of global cities together with increased population mobility and a heightened concern regarding climate change and energy independence have increased interest in electric vehicles (EVs) as one means to address these challenges. The development of a public charging infrastructure network is a key element for promoting EVs, and with them reducing greenhouse gas emissions attributable to the operation of conventional cars and improving the local environment through reductions in air pollution. This paper discusses the effectiveness, efficiency, and feasibility of city strategic plans for establishing a public charging infrastructure network to encourage the uptake and use of EVs. A holistic analysis based on the Value Creation Ecosystem (VCE) and the City Model Canvas (CMC) is used to visualise how such plans may offer public value with a long-term and sustainable approach. The charging infrastructure network implementation strategy of two major European cities, Nantes (France) and Hamburg (Germany), are analysed and the results indicate the need to involve a wide range of public and private stakeholders in the metropolitan areas. Additionally, relevant, and fundamental patterns and recommendations are provided, which may help other public managers effectively implement this service and scale-up its use and business model.

1. Introduction

As a result of the unprecedented phenomenon of a steady growth in city populations, it is now crucial that urban areas provide sustainable solutions (Pujadas, Cavalaro, & Aguado, 2019; Pujadas, Pardo-Bosch, Aguado-Renter, & Aguado, 2017; Roigé, Pujadas, Cardús, & Aguado, 2020), especially for mobility. The mobility industry alone is one of the major contributors to this ecological destabiliser, accounting for about a quarter of GHG emissions (Napoli, Polimeni, Micari, Andaloro, & Antonucci, 2020) worldwide and one-fifth of total CO2 emissions in Europe (Vijayashree & Ganesan, 2020).

After decades in which the traditional internal combustion engine (ICE) has been the dominant automotive powertrain, signs of a shift toward fully electric powertrains are becoming apparent (Adnan, Nordin, & Bahrudin, 2019; Liu & Wei, 2018; White & Sintov, 2017; and Huang, He, Gu, Wood, & Benjaafar, 2015) and there is reason to believe that in the short-term, there will be a period of maturation and a rise of the EV1 (electric vehicle) industry (Perera, Hewage, & Sadiq, 2017). Such a momentum for the EV in the years ahead is aligned with the European Commission strategy (European Commission, 2010a, 2010b, 2010c), which explicitly supports clean fuel transport and proposes specific objectives for enabling infrastructure deployment. Reducing environmentally harmful emissions (both CO2 and NOx) is one of the key reasons (Vaidya & Moutfah, 2020; and Wang, Lia, Xua, & Li, 2020), but other considerations also play a role—such as economic benefits, gaining a technological edge to keep the value chain in the country, the desire for greater energy independence, and a shift towards a less oil-intensive transport sector.

Consumer demand, industry technology developments, as well as government stimuli and regulations are the three main forces that drive the adoption of electric mobility in Europe (Biressiologlu, Kaplan, & Yilmaz, 2018; Bubeck, Tomaschek, & Fahl, 2016). As these forces gain

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1 In this paper, we refer to EVs (electric vehicles) as all vehicles for which an electric motor is the primary source of propulsion. This includes plug-in hybrid electric vehicles, range-extended electric vehicles, battery electric vehicles, and fuel cell electric vehicles, but excludes (conventional) hybrid electric vehicles.

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strength, EV market share will expand. According to BCG (2019) by 2030, EVs are expected to account for 50%–60% of new car sales. If consumers purchase EVs at the expected rates over the next five to ten years, a lack of charging infrastructure could become an obstacle to EV adoption (Engel et al., 2018).

A growing EV charging station infrastructure seems inevitable to achieve the future challenges of mobility. The automobile and battery industries have made considerable technological progress with various solutions to overcome important hurdles for mass market sales such as an optimised charging infrastructure deployment with the aim of maximising EV service levels (Anjos, Gendron, & Joyce-Moniz, 2020; Gan, Zhang, Hang, Qin, & Jin, 2020; Tao, Huang, & Yang, 2018; Xi, Sioshansi, & Marano, 2013), minimised marginal greenhouse gas emissions from power generation (Tu, Gai, Farooq, Posen, & Kan, 2019), and even queuing behaviour studies (Xiao, An, Cai, Wang, & Cai, 2020). Nevertheless, the deployment of EVs is still at an early stage and there is a long path to go (Zhang, Zhao, & Kan, 2019). The installation and commercial exploitation at the required scale of a public charging infrastructure, or a public charging station (CS) network, is a key mechanism to facilitate mass EV adoption because it improves availability and accessibility, reduces range anxiety, and enables the use of EVs for long distance travel (Palomino & Parvania, 2019). Nevertheless, it represents a cost that is too high for governments and public administrations to bear alone. Consequently, making a public charging station business model is a challenging issue that needs further research.

Various authors state that there is a chicken-and-egg dilemma among EV deployment and the formation of a CS network (Mak, Rong, & Shen, 2013 and Shi, Hao, Lv, Cipcigan, & Liang, 2020). The conflict exists between EV owners and CS operators. Consumers are averse to buying EVs until they can be sure that sufficient charging facilities will be available at an affordable price. Meanwhile, CS operators are unwilling to invest until they can be assured of a minimum profitability that is not possible at this stage due to low utilisation rates and high up-front costs (Springel, 2016).

Hence, the question is how to solve this business contradiction and drive this green technology. Eid, Guillén, Marín, and Hakvoort, (2014) states that governments support is needed. However, academics have rarely discussed how governments can develop an implementation strategy for the establishment of a CS network (Shi et al., 2020). For this to occur, a detailed understanding of the factors underpinning the business case development for CS networks is needed. To the best of the authors’ knowledge, none of the academic studies develops a holistic analysis of such a business case development at municipal level. Aware of that concern, this paper uses the Value Creation Ecosystem (VCE) and the City Model Canvas (CMC) to analyse and compare, from a business perspective, two major interventions for deploying public charging infrastructures being implemented in two European cities (Nantes and Hamburg). The goal of this analysis is to capture the principal needs and challenges, and identify governance recommendations for local authorities, which serve as a basic approach for defining an appropriate city strategy (Nilashi et al., 2015). Those cities capable of learning from other cities will prosper in the future (Calzada, 2020).

This paper is divided into six sections. Having outlined the aims of the research and its significance in the introduction, Section 2 presents a review of the literature on electric mobility. In Section 3, the paper discusses the methodologies used in the study. In Section 4, the case studies of Nantes and Hamburg are analysed in depth. Section 5 then discusses strategies for implementing and scaling up this type of project. Finally, the conclusions are presented in Section 6.

2. Literature review

Electric vehicles (EV) are those vehicles powered partially, or entirely, by onboard electric motors supplied with energy by batteries which are charged with a plug through an electric outlet (Liu & Wei, 2018 and Wang, Li, & Zhao, 2017). Technological developments in electric motors and batteries are making this type of vehicle a viable solution for supporting a ‘green’ transportation system (Lou, Huang & Gupta, 2017; and Sachana, Debb, & Singh, 2020). Cities are crucial to achieving this ambitious objective (Yin, Laing, Leon, & Mabon, 2018) and for contributing to sustainable development. Urban sustainability must consider a global approach based on social inclusion, financial viability, and ecological preservation (Huang, Yan, & Wu, 2016; Lopez-Carrero & Monzon, 2018; Pardo-Bosch, Aguado, & Pino, 2019). Recently, urban studies are paying special attention to the social and economic axes of sustainability (Biyukozkun & Karabulut, 2018; and Ferrer, Thomé, & Scavarda, 2018), which is seen by several authors (Addanki & Venkataraman, 2017; Shealy et al., 2018; and Yin et al., 2018) as a challenge and an opportunity.

According to Abergel et al. (2020), the EV global stock reached 4.8 million in 2019, 47 % of which are used in China and 25 % in Europe. Although there is an increase of sales year by year, the adoption of EV is still extremely low when compared to the overall vehicle stock; just five countries have an EV market share greater than 1.5 %. From the EV buyer perspective, the main barriers include the greater initial investment, even if running costs are lower for EVs when compared to internal combustion engine (ICE) vehicles (Madina, Zamora, & Zabala, 2016), the range anxiety related to uncertainty about whether an EV can cover all necessary journeys without long deviations for charging (Napoli et al., 2020), and especially, the lack of an efficient network of CSs (Needell, McNerney, Chang, & Tranck, 2016).

Charging stations can be grouped into different categories depending on their accessibility, charging level, type of connection, and charging strategy (Kley, Lerch, & Dallinger, 2011). Considering accessibility, stations can be classified into private, semi-public, and public (Funke, Gnaß, & Plötz, 2015). Private CSs, which are installed at homes in personal car parks, can generally only be used by one household. Semi-public CSs can be used indistinctly by a group of people belonging to a restricted community, such as those present at workplaces. Finally, public CSs are in accessible places and open to all users. Deilami and Muyeen (2020) states that there are three charging levels: level 1 (slow chargers), which need 10–13 hours to fully recharge; level 2 (fast chargers), which need 1–3 hours to fully recharge; and level 3 (rapid chargers), which need 30–100 min to fully recharge. Private CSs are usually slow chargers, fast at best. Most public CSs are fast chargers, and some are rapid chargers.

Home charging using a private CS during night hours is the option preferred by most owners. In fact, almost 90 % of daily trips can be done with a night-time home charging (Sun, Chen, & Yin, 2020). However, in several urban areas, especially in large cities, where dedicated parking facilities are limited, private CSs are rare, and very few EV owners have access to domestic charging infrastructures. Hence, most EV owners in such settings rely on public CSs to recharge their vehicles (Perera, Hewage, & Sadiq, 2020). Moreover, long-distance trips usually need on-route charging in public CSs (Needell et al., 2016).

Nevertheless, according to Bunsen et al. (2019), there are just 539,000 public CSs worldwide, half of which are in China, and the growth rate and the number of chargers per vehicle are decreasing. The limited deployment of public CSs is due to the high upfront costs necessary to develop a reliable network (Madina et al., 2016), and the existing demand compromises the profitability of these facilities and does not justify investment with long payback periods (Morton, Anable, Yeboah, & Cotrill, 2018). This creates a ‘chicken and egg’ dilemma (Boiland, 2017; Shi, Wang, Liu, & Jin, 2019). Paradoxically, an adequate public CS network is frequently mentioned as a requirement to guarantee the uptake of this type of mobility (Haustein & Jener, 2018).

Public administrations are willing to make efforts to support the diffusion of EVs. Many have developed specific regulations that grant privileges to EV owners, which may include unrestricted high occupancy vehicle lane access, reduced registration and road taxes, free parking, and unrestricted access to city centres (Clark-Sutton et al., 2016). Municipalities are trying to lead by example, electrifying public transport
and municipal fleets, and developing public CS networks. By deploying a CS network, public managers aim to coordinate network development and balance interests between EV users and charging infrastructure investors (Shi et al., 2020), which should include the installation of public CSs in public spaces —such as municipal car parks, civic centres, and residential streets— and semi-private spaces —such as supermarkets, shopping centres, and leisure centres— (Palanca, Jordán, Bajo, & Botti, 2020) to guarantee effective coverage. Development of the operational management of CSs needs to contemplate the value created and captured by many participating actors (Luo, Huang, & Gupta, 2017), especially: EV owners; local government; electro-mobility service providers (EMP); and charging service operators (CSOs). According to Perera, Hewage & Sadiq (2020), EMPS offer a direct contract to EV owners, which provides access to charging facilities, including search, find, and routing to public CSs and other services in a business-to-consumer commercial relationship. CSOs manage and maintain charging stations, as well as providing charging services to EMPS, including energy, in a business-to-business commercial relationship. CSO services can be offered by the municipality or by a private company through an outsourcing or public-private partnership contract. Depending on the market context and development, CSOs may also assume the EMP role to offer a vertically integrated solution. However, Fang et al. (2020) states that the high risks, led by the lack of regulation standards and market uncertainty, continue to hinder the entry of private firms in this sector and public intervention is needed to support the establishment of public CS networks.

To promote the development of effective public CS network strategies, public authorities can use private-sector tools to conduct a holistic and accurate assessment of commercial potential. Williams and Lewis (2008), Duggan and Moon (2008) and Timeus, Vinaixa, and Pardo-Bosch (2019) recommend using business models to conduct this assessment, as this tool allows public managers to understand what they need to create and deliver public value. Business models from a public management perspective are not solely targeted at the goal of making a profit; they can also be focused on achieving social and environmental benefits (Pardo-Bosch, Cervera, & Ysa, 2019). However, most researchers working on public CS networks have focused their attention on studying facility location problems from different perspectives (Brüinl, Harries, McHenry, & Wager, 2020). Thus, they have considered this issue in terms of how to structure a public CS network to enable EVs to effectively circulate without running out of range. Others have dedicated their efforts to improving key CS technologies, such as battery efficiency optimisation and wireless charging technology, or charging service patterns, such as payment mechanisms and pricing models (Liu & Wei, 2016). While these represent important issues, they overlook the need to develop sustainable business models to underpin the financing of such networks.

3. Methods: business model tools for the analysis

The case study method was chosen to address the objectives previously highlighted. The case studies selected for this research were chosen from pilot implementations in Nantes Métropole (France) and Hamburg (Germany) implemented under EU H2020 project mySMAR- TLlife to establish public CS networks and stimulate the adoption of EVs by private owners.

To identify the key elements of the business model, and ultimately examine the opportunity to scale-up and replicate the intervention, two different business model tools are used: the Value Creation Ecosystem (VCE) and the City Model Canvas (CMC). In the following, both tools are presented.

3.1. Value Creation Ecosystem

When dealing with business models, the whole ecosystem (including industry and stakeholders) must be considered due to the complex interactions between stakeholders, many of which were not part of the value chain of ICE vehicles nor the electricity supply (Kley et al., 2011).

An ecosystem is an interconnected set of services enabling users to fulfill a variety of needs in one integrated experience. For cities, analysing the ecosystem of each business model is a key activity for answering the following important questions: what are the activities needed to create value for the ultimate beneficiaries? Who are these ultimate beneficiaries? What actors/stakeholders are necessary to develop these activities? What are the values captured?

An analysis of the implications of innovative business models in multifaceted environments, as electro-mobility is, requires a global approach to ensure that all the involved actors obtain a benefit (Madina et al., 2016). Such an approach must be carried out by assessing:

a) The industry opportunities and outlook, which can provide a view on how much value is on the table. Important factors include: market size; growth potential; competitive strategy; and profitability.

b) The city’s strengths to see if there is a natural owner of a given opportunity. Important factors include: existing customer base and access to valuable data; relevance to core business and capabilities; existing partnerships; networks; and sister companies to leverage.

To couple and study all these ecosystem factors, Rowley (1997) and Key (1999) presented the network model, which explains the multilateral contracts among the stakeholders participating in a project, but does not describe what kind of relations exist between actors and what value they each create for the entire ecosystem. Tian, Ray, Lee, Cao, and Ding, (2008) offers another model to assess, in different scenarios, the value distribution among the stakeholders involved in the production of services. This tool is based on multiagent systems and game theory analysis, which ensures its consistency and robustness, as well as making it complex and difficult for practical and frequent use. For its combination of rigour and usability, Pardo-Bosch, Aguado et al. (2019), Pardo-Bosch, Cervera et al. (2019) propose to apply the Value Creation Ecosystem (VCE) to construct the stakeholder network for a particular business model. VCE (Fig. 1) connects each actor (represented by a node) to as many other actors (nodes) as necessary. Each relation between two connected nodes (i.e., node A and node B) generates two links: one indicates the value that actor A creates for actor B, and another from actor B to actor A represents the value that A captures from its relation with B (payback).

3.2. City Model Canvas

The business model canvas (BMC), proposed by Osterwalder and Pigneur (2010), is a chart tool which visually represents through nine blocks (value propositions, customer segments, channels, customer relationships, revenue streams, key partners, key resources, key activities and cost structure) the different elements of a business model and the potential interconnections and impacts on value creation (Bocken, Short, Rana, & Evans, 2014; Wallin, Chirumalla, & Thompson, 2013) to align profit and purpose to support a more sustainable value creation model. Some limits of the BMC template are its focus on profit or economic value orientation (Coes, 2014; Upward, 2013) and its subsequent conceptual isolation from its environment, whether this is related to: (a) the industry structure or to stakeholders (solved with the VCE analysis); or (b) society and the natural environment.

To overcome this drawback, researchers have extended (Díaz-Díaz, Muñoz, & Pérez-González, 2017; Díaz-Díaz, Muñoz, & Pérez-González, 2017; Joyce & Paquin, 2016) and applied (Díaz-Díaz et al., 2017a) the original business model canvas to non-profit business models by adding two additional blocks: (1) social and environmental profit; and (2) social and environmental cost (both collect a number of not purely economic values that are important when making decisions that affect society).

In a further extension, Timeus et al. (2019) adapted the BMC for use in cities and public administrations by replacing several blocks of the
canvas with others that are more closely related to public operations, and proposed a framework called the City Model Canvas (CMC). The CMC is composed of 14 blocks (see Fig. 2), divided into four main areas:

1 Value proposition, which states what benefits are created and which problems will be solved by the organisation through smart services. In the CMC, the value proposition usually encompasses improved quality of life in an urban environment that is economically prosperous, environmentally responsible, and socially inclusive. A clear value proposition will help city council managers focus their key activities on the delivery of that value.

2 Delivering value, which includes the identification of: (a) the direct beneficiaries of smart services; (b) whose support (buy-in) must be obtained for the successful implementation of a project; and (c) the deployment of the plan to guarantee that services will be delivered or accessed.

3 Producing value, which includes: (a) the key partnerships whose support is essential; (b) the key activities that the city council must execute to ensure the model’s effectiveness; and (c) the key resources and infrastructure needed to implement the projects (which make reference to the financial and physical assets the city, as well as the political and strategic resources, such as regulatory frameworks).

<table>
<thead>
<tr>
<th>Mission statement</th>
<th>What is the ultimate goal that the city seeks to achieve?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Partnerships</td>
<td>Who can help the city deliver the value to the beneficiaries? Who can contribute key resources?</td>
</tr>
<tr>
<td>Key activities</td>
<td>What must the city council do to create and deliver the proposed value?</td>
</tr>
<tr>
<td>Value Proposition</td>
<td>What specific problems does the proposed service solve or alleviate?</td>
</tr>
<tr>
<td>Key infrastructure and resources</td>
<td>What key resources does the city council have to create and deliver the value?</td>
</tr>
<tr>
<td>Buy-in &amp; support</td>
<td>Whose buy-in is needed in order to deploy the service (legal, policy, procurement, etc.)?</td>
</tr>
<tr>
<td>Beneficiaries</td>
<td>Who will directly benefit from the proposed services?</td>
</tr>
<tr>
<td>Budget cost structure</td>
<td>What is the cost structure for the city of the proposed services?</td>
</tr>
<tr>
<td>Revenue streams</td>
<td>What sources of revenue for the city do the proposed services provide? What other sources of revenue does the city have?</td>
</tr>
<tr>
<td>Environmental costs</td>
<td>What negative environmental impacts can the proposed services cause?</td>
</tr>
<tr>
<td>Environmental benefits</td>
<td>What environmental benefits will the proposed services deliver?</td>
</tr>
<tr>
<td>Social risks</td>
<td>What are some of the potential social risks that the proposed service entails? Who is most vulnerable as a result?</td>
</tr>
<tr>
<td>Social benefits</td>
<td>What social benefits will the proposed services bring about?</td>
</tr>
</tbody>
</table>

Fig. 2. The City Model Canvas (CMC) presented by Timeus et al. (2019).
The triple-layered bottom line which represents the assessment of the economic, environmental, and social costs and benefits of the proposed service. The first bottom line shows the economic viability of the actions. It compares expected costs and revenues and forces the city council to consider how it will finance services. The second ‘bottom line’ is the environmental balance of the planned interventions. It compares the potential environmental benefits and costs of the project. The third bottom line, social sustainability, compares social benefits and social impacts (the negative costs that the project can have on residents and communities, such as excluding certain groups from services or increasing living costs in some areas). Any trade-offs between these three ‘bottom lines’ would become apparent in the discussion of the CMC (e.g., a smart service may produce a high environmental benefit, but also a high social cost) and can be negotiated with stakeholders before implementing decisions.

According to Pardo-Bosch, Aguado et al. (2019), Pardo-Bosch, Cer- vera et al. (2019), the CMC — which has also been successfully applied in Grossi, Meijer, and Sargiacomo, (2020) — represents a useful tool that city councils and public administrations can use to assess, from a holisitic perspective, the net balance of their policies and actions when designing new business models which can deliver on multiple objectives.

4. Case studies

This section uses the CMC and VCE (previously explained in Section 3) to analyse the initiatives that Nantes Métropole (France) and Hamburg (Germany) are developing as pilots under EU H2020 project mySMARTLife to establish public CS networks to stimulate the adoption of EVs by private owners. For this study, both municipalities applied the VCE and CMC through various workshops with a group of stakeholders involved in CS network deployment. Complimentary insight into the application of VCE and CMC was gathered through semi-structured interviews with members of the city councils, who are overseeing these interventions in the mySMARTLife project.

4.1. EV charging infrastructures in Nantes Métropole

Nantes is the sixth largest city of France with 600,000 inhabitants (including the metropolitan area). The population of Nantes has increased by 22 % over the last 25 years and 100,000 new residents are expected by 2030. The major challenge for Nantes is to keep a high standard of sustainable urban planning development. As part of their mobility initiatives, Nantes Métropole launched various initiatives for EV charging infrastructure.

The currently available CS network for EVs in Nantes consists of 21 CSs located in publicly accessible multi-storey car parks, with 87 e-bike CSs also in multi-storey car parks (all managed by private operators through public tendering).

Nantes Métropole is in the process of installing an additional 125 public CSs until the end of 2021, which will be linked to Nantes’ engagement portal to provide information such as CS availability and location to users. At least 14 will be rapid CSs in surface car parks, with 2 being fast CSs in enclosed car parks. One rapid and 4 normal CSs will be on the west side of the Ile de Nantes, in a new urban area called Quartier de la Creation, which will be a neutral multimodal hub. These five stations will be powered by renewable electricity supplied by a photovoltaic array on the roof and a hydro-power micro-station. In addition, 12 CSs will be installed for e-buses.

4.1.1. Intervention value chain

The implementation of a reliable EV CSs network is a complex intervention that requires the participation of various actors — as can be seen in the VCE presented in Fig. 3. The VCE of the public CS network in Nantes provides a clear vision of the value chain, as well as the services, gains, and payback relations between every stakeholder.

Nantes Métropole (i.e., the municipality) is the project owner. Nantes Métropole tenders the service for the management of the CSs to private operators who already run the public car parks. The private operators of the public car parks act therefore as CSOs for the case of the EV charging station business model. These CSOs manage the relation with the EV owners and suppliers (energy, charging point manufacturers, and other type of suppliers such as ICT services).

EV owners pay a higher fee to park in the bays that have CSs than ICE vehicle owners pay to park in non-CS bays. These higher fees incorporate the energy supply to charge the EVs. The main role of the research and technology organisations (RTO), together with the ICT Department of Nantes Métropole, is to capture and analyse the data on CS operation. The municipality uses these data to evaluate and monitor the intervention, as well as to gather better information on mobility issues for EV owners, such as real-time information on the availability of bays. The CSs send the data to the municipality, which provides the occupancy information in the ‘Engagement portal’ of the city (website) and in ‘Nantes in my pocket’ (mobile application). These are the main channels to inform EV owners and the public about various issues of daily life in Nantes.

4.1.2. City business model

The city business model, articulated through the City Model Canvas (Fig. 4) and detailed across this subsection, explains how the municipality plans to install EV charging stations in the city in a way that is economically viable, socially inclusive, and environmentally sustainable, with the aim of reducing pollution and improving public wellbeing as part of its public value delivery.

The value proposition of the business model is to encourage and facilitate the use of EVs through the provision of CSs and parking bays in public car parks. To this end, cities are considering ways to diversify their established parking services to also cater for the charging needs of EV owners.

The direct beneficiaries of the intervention are EV owners. These owners benefit from more spaces to park and charge their vehicles. Obviously, considering the mission statement, the business model has indirect beneficiaries, such as members of the public who will benefit from the reduction of local air pollution and greenhouse gases. As will be seen at the end of this section, the business model brings other environmental and social advantages, which are beneficial for residents and the city itself.

The intervention has significant political support behind it. However, the municipality is working to ensure the citizens buy-in, especially those car owners who use public spaces to park their vehicles at home or
at work, because they could be affected by the reduction of parking spaces for conventional vehicles.

Regarding key activities, and beyond the classic project management activities, such as the public tender design to run CSs in public car parks, it is important to mention that Nantes Métropole offers various advantages to EV owners, such as free electricity to charge and security measures to leave vehicles in the parking spaces, with the aim of encouraging the use of parking and CSs. Other important activities include educational and training programmes for citizens, technicians, and operators on the electromobility sector and CS features.

One key resource which this model relies on is the information provided by the ‘Engagement Portal’ (website) and ‘Nantes in my pocket’ (mobile application). These are two channels offering information and real time data to EV owners (for example, on parking and charging availability). These information resources make the process much more efficient for the municipality in terms of data, and for the private operator in terms of management. It is also important, at least in an initial phase, to justify the financial support provided to the project by demonstrating the level of public engagement.

Key infrastructures include parking spaces to allocate to the charging stations; the need to have a powerful internet network structure and servers to enable connectivity and data transfer; and the urban platform that will be connected to the CSs to record charging data.

Finally, the sustainability of the business model focuses on the triple bottom line: costs/revenues; environmental costs/benefits; and social risks/benefits. Fig. 3 shows that Nantes Métropole has two main revenue sources: fees from users and municipal tax revenue dedicated to this public service. Regarding fees, 50% of the price charged for parking and charging returns to the municipality, and the other 50% goes to the owners of the car parks. Nantes Métropole can charge the CSO because it sets the conditions of the tender for the management of public car parks and has integrated this new CS service. The integration of the charging facilities as one of the public parking services is seen by the municipality as an opportunity to cut budget costs in the future due to its consequent operation optimisation. In this phase, the municipality is also the recipient of an EU grant (short term) for financing the start-up costs of the public CS network. The budget costs of the business model are mainly Capex (i.e., expenditure in charging infrastructure); however, it must pay for the operating cost of auxiliary infrastructures such as the mobile app or the website and the key activities described above. Although the municipality offers technical support on the operation and maintenance of the CSs, both activities are —according to the public tender— the responsibility of the operator.

The business model presents important environmental benefits such as the reduction of local air pollution emissions that directly influence the quality of life, the reduction of fossil fuel consumption due to an increase of EVs, and the decrease in environmental noise, which also affects daily life. Regarding environmental costs, the authors must highlight that an increase of the number of EVs is linked with the consumption of electricity, which also has an environmental impact attributable to the emission factors associated with generating a given kilowatt hour of electricity.

Finally, as has been mentioned during the analysis, there are important social benefits. The main ones are the improved health of urban residents and the improvement in citizens’ wellbeing from improved air quality due to the removal of ICE vehicles. Obviously, the intervention contributes to the smart ecosystem development and the scale-up of the solution could imply an economic development for the city in terms of job creation, attraction of companies and start-ups, as well as outside investment. In addition, promoting the general use of EVs and establishing Nantes Métropole as a pioneer in low-carbon mobility will likely increase the citizens’ environmental awareness. In terms of
The city business model, which is articulated through the City Model Canvas (Fig. 6) and is explained in this subsection, illustrates how the municipality of Hamburg plans to implement a sustainable strategy to deploy a CS network to encourage the use of EVs that should imply a decrease in greenhouse gas emissions, and by extension, a reduction in city pollution. More precisely, the municipality aims to extend its public CS network to provide a wider coverage across the city by deploying CSs in both public and private spaces and reducing charging times through fast and flexible CSs, which will also facilitate intermodal e-mobility based on e-car sharing.

The principal beneficiaries are the EV owners since all the interventions focus on offering smart solutions to tackle some of the problems facing owners. Hamburg’s inhabitants are indirect beneficiaries because the use of EVs directly reduces CO₂ emissions, as well as

4.2.1. Intervention value chain

The VCE of Hamburg’s intervention (Fig. 5) presents the actors involved in the deployment of e-mobility services and the commercial relations established among them. The municipality acts as the project promoter, and Stromnetz (the city-owned utility company) acts as the owner of the public CS network. Stromnetz is the operator of the Hamburg energy distribution grid and is involved in the planning of charging facilities, as well as in the further development of the intelligent IT backend in the project area.

The city of Hamburg uses its public structure to set the conditions for expanding the electromobility sector and market. Stromnetz controls the value chain of the business model and acts as the main operator for the public CS network in the city of Hamburg. As a public company, it installs CSs in public spaces that the municipality controls. The CSs are the essential channel for running this business. The scheme introduces a new key actor to enable the use of this channel, the electric mobility providers (EMPs). The EMPS have direct contracts with EV owners, through which they offer them access to CSs installed by Stromnetz, creating a business-to-consumer commercial relationship. The EMPS also have commercial agreements with the energy firm (business-to-business relationship) that provides energy to the CSs that EV owners use when recharging their vehicles. The EMPS who receive payments from EV owners are responsible for processing the transaction and allocating the revenue to the appropriate agents (the energy supplier and the CS operator), although Stromnetz is currently offering this service for free.

4.2.2. City business model

The city business model, which is articulated through the City Model Canvas (Fig. 6) and is explained in this subsection, illustrates how the municipality of Hamburg plans to implement a sustainable strategy to deploy a CS network to encourage the use of EVs that should imply a decrease in greenhouse gas emissions, and by extension, a reduction in city pollution. More precisely, the municipality aims to extend its public CS network to provide a wider coverage across the city by deploying CSs in both public and private spaces and reducing charging times through fast and flexible CSs, which will also facilitate intermodal e-mobility based on e-car sharing.

The principal beneficiaries are the EV owners since all the interventions focus on offering smart solutions to tackle some of the problems facing owners. Hamburg’s inhabitants are indirect beneficiaries because the use of EVs directly reduces CO₂ emissions, as well as
concentrations of local air pollution (NO\textsubscript{x}, PM, etc.). Furthermore, the business model stimulates the EV sector and its main players, such as the electromobility providers (EMPs) or the future charging stations operators (CSOs), who are all considered key partners. Finally, EV manufacturers will also benefit indirectly through facilitating the adoption of these vehicles, which is a particularly important industry for a country like Germany due to its automotive heritage.

It seems clear that there is the political will for encouraging EV adoption in Hamburg since the master plan launched in 2015 set the conditions for the EV ecosystem in the city. Another important buy-in comes from the public regarding the use of public spaces for CSs. The reason is that some of the citizens do not want to loss places to park their ICE cars in the street. Many people agree with EV policies, but their most relevant mantra is ‘do not take my parking space’. Finally, there is also the retail market buy-in, which could use EV for last-mile delivery. It is crucial to engage EV players and set the conditions to establish an attractive value chain for private companies to offer a good service for EV owners.

The city business model involves different types of key activities. On the infrastructure side, it is strategic for city objectives to identify the best locations to install CCs, as well as types of charging structure in terms of conditions for EV owners. On the customer side, it is also strategic for the business model to stimulate demand. Such action implies a set of activities regarding EV owners. It is important to line up all the possible advantages related to purchase and usage, such as tax advantages offered by the German government, or free parking. Beyond that, the municipality needs to provide educational and training programmes for all the agents involved in the provision model—such as technicians and operators—to familiarise them with the new solutions. These programmes should be based on updated data and information from monitoring and evaluation activities of the public charging interventions to provide continuous learning about solutions.

The city of Hamburg is pushing hard to build the structural conditions for the development of the EV ecosystem, such as clusters, networks, and logistics through the master plan to set the city strategy for EVs. In addition to these aspects, parking spaces and CSs are key resources. The main infrastructures, besides the CSs themselves, are a powerful internet network structure and servers to enable capacity, connectivity, and data transfer.

Regarding the triple bottom layer, the municipality covers capex costs (i.e., expenditure in charging infrastructure) and opex costs (i.e., operating expenses for the services). The sources of revenue in this model are quite weak at this stage but serve to cover the implementation of the city’s strategy. The main income comes from municipal taxes and EU funds. The municipality does not obtain revenue (fees) from EMPs since Hamburg wants these players on board, and wants as many as possible, nor from the CSO (Stromnetz). The idea is to provide the best possible services to EV owners. For the scale-up and replication of the intervention, the strategy is that Stromnetz (initial charging operator) will request payments from the EMP for enabling EV owners to charge in their physical stations. The second step could be to manage through public tender the rental of the stations to private CSOs, which will assume the opex cost, and so significantly reduce costs for the city of Hamburg. These companies will install new facilities for charging EVs.

The environmental impact, as it has already been presented in the case of Nantes, is highly positive. The impact can be summarised in less fossil fuel consumption, due to fewer ICE vehicles; a reduction of air pollution (CO\textsubscript{2}, NO\textsubscript{x} gases and PM) that will improve air quality for residents; and a decrease in environmental noise. Regarding the environmental costs, there will be an impact on energy use during the installation of CSs, which will have a short effect, and the impact of increased electrical consumption. In terms of social benefits, the municipality points to the increase of environmental awareness of the public, an improvement and increased use of the smart social ecosystem development, an improvement in quality of life, the health benefits better standards of traffic management and levels of air quality, and economic developments linked to the ecosystem and innovation clusters for electromobility. However, Hamburg considers that there is the risk of making the city less attractive for CSOs in the short-term due to the strong role of public entities. This is crucial because the objective of the
city of Hamburg is to set the conditions, initially through the public sector, to create an attractive market for private companies such as SMEs, CSOs, ICT companies, and car companies. It is important that the municipality knows precisely where, and to what extent, private operators should be involved, especially CSOs.

5. Discussion

5.1. General analysis

The strategies that Nantes Métropole and Hamburg are applying in the deployment of public CS networks share similarities and differences which partially reveal the variety of business models that are applicable in this emerging market and offer an interesting overview of the key aspects to consider from a city point of view when deploying a CS public network. The main goal of the municipalities is to reduce greenhouse gas emissions and local air pollution to improve the health of residents and mitigate the negative impacts of climate change. Electric vehicles, especially electric cars, already represent a real alternative to ICE vehicles worldwide. Although there are still relatively few EVs on the streets, the market is expected to expand dramatically in the short to medium term (Aberge et al., 2020), and this is a trend that seems highly likely to continue. This is a growing sector and the market remains in its infancy. There are currently few private actors who have developed sustainable CS network business models. To ensure its consolidation, public administrations must support this sector by deploying CSs in early stage. Having a public CS network fulfill demand is a salient issue for promoting EVs and, although public authorities are playing and will continue to play a crucial role in the transition from ICE vehicles to electric vehicles, it is essential to involve private as well as citizens in the process.

According to the study results, the success of this type of intervention depends on a strong commitment from municipalities, which should lead to the establishment of public charging infrastructure for EVs, as well as installations in various locations when private enterprises are unwilling to play this role. However, the value chain of the interventions projected in both cities reveals a clear public-private-structure, which is, according to Wu, Song, Li, and Xu, (2018)), key to attracting private capital. The municipalities represent the public sector promoting the interventions, while the CSOs, EMPs, and energy companies represent the private sector, providing different types of values that make viable ecosystems for EV owners. The public sector participation reduces the perceived risk of intervention and provides security to private sector actors in this emerging market.

It is advisable for most cities, as did Nantes Métropole, to tender the management, operations, and maintenance activities of charging stations to CSOs, which can also manage public parking spaces where the stations are installed. However, if a municipality has a robust structure of publicly owned companies, it is possible to keep these activities in-house—as Hamburg does through Stromnetz. In fact, Hamburg uses Stromnetz as a CSO and offers open spaces for installing CSs, while Stromnetz creates the conditions for an attractive market for private companies. In any ecosystem, CSOs play an essential role and could be the actors that capture the most important part of the value created in this business.

Beyond that, the German case shows how to incorporate EMPs separately from the CSOs. The EMPs provide greater versatility and openness to the service, increasing the number of potential customers and adding value to the ecosystem, and therefore it seems evident that in advanced stages of the implementation both roles should be played by different actors. In this scheme, the CSOs and EMPs share the value captured in the charging process. Nowadays, users often have limited technical knowledge, so it is complicated for them to distinguish between EMPs, so a differentiation, a priori, will only be achieved through the price of recharge.

The value propositions of the business models for the CS interventions are generally similar in developed countries and they state the benefits that any reader can expect. In general terms, the value propositions mention the promotion of EVs, an increase of efficiency in charging processes, and a reduction of energy consumption from fossil fuels. These aspects clearly follow the new objectives of the European Parliament (Directive (EU), 2019) relative to the promotion of clean and energy-efficient road transport vehicles. This Directive is expected to result, in the longer term, in a wider deployment of clean and energy efficient vehicles.

One of the main differences among city strategies can be found on the deployment block, in most cases, due to the difference in the total number of already existing public CSs in each city. Municipalities facing an early-stage implementation (as is the case of Nantes) should prioritise increasing the number of CSs for covering as much surface as possible (i.e., a maximum coverage approach). For doing this, it is recommended to install CSs in public car parks, because the value proposition in this phase should be focused on facilitating access to CSs in public spaces. Whereas municipalities at a later stage (as is the case of Hamburg) should concentrate their efforts on improving the user experience by installing fast CSs which can be easily used by any EV owner (without forgetting the logical need to extend the coverage across the city and add capacity around sites which prove popular). Therefore Hamburg focuses on fast and flexible charging processes to support all relevant charging standards, and on parking space detection to contribute to a higher utilisation (a spatial optimisation approach) and thus the profitability of public CSs. These technical aspects are crucial since they create additional customer benefits that can compensate one of the main challenges for scaling up EVs, such as high initial investments (Bohnsack, Pinkse, & Kolk, 2014).

Regarding the direct beneficiaries, any deployment of public CSs focuses on EV owners, and, on e-car owners who are willing to park in public spaces. Following Hamburg’s example, in advanced stages it is possible to shift the concept of owners to users, positioning the charging infrastructure for intermodal and flexible use (such as through car sharing users). Furthermore, CSOs and EMPs can also be considered as beneficiaries since this type of intervention encourages the wider EV ecosystem to enable them to operate and develop their businesses. Finally, citizens are clear indirect beneficiaries because EVs do not emit tailpipe CO₂ and other pollutants such as NOₓ.

For city business models to succeed in this field, they need to include at least the following five key activities: (1) offer and promote advantages for the adoption of EVs (such as tax advantages, financial support for purchasing EVs, and free parking) to encourage inhabitants to purchase an EV; (2) develop educational and training programmes for citizens, technicians, and operators to become familiar with electromobility services, 3) identify locations to install CSs as a strategic fact to satisfy real and potential demand (Pagany, Ramirez Camargo, & Dorner, 2019); 4) select the appropriate type of CSs (technical characteristics) to achieve charging goals; and (5) monitor the usage and the operation of the public CS network to improve the service. Beyond that, another important activity is the public tender design for managing CSs.

Concerning key resources, it is crucial to have smart solutions to tackle specific problems such as data security and billing. Aside from this resource, it is interesting to highlight the ‘Engagement Portal’ (website) and ‘Nantes in my pocket’ (mobile application) as information resources for electromobility developed by Nantes Métropole. These resources offer real time data about aspects such as parking spaces and charging availability. Cities also need a powerful internet network structure and servers to enable connectivity and data transfer to specific data analysis departments and/or the urban platform. Moreover, for ensuring a long-term sustainability, it is essential to develop a cluster related to electromobility (energy companies, innovative solutions, start-ups, etc.), which provide a network and adequate logistics for the EV ecosystem.

As regards the triple bottom layer analysis, the easiest way is to start with the environmental and social aspects and leave the discussion on budget costs and revenue streams for last. Municipalities all want to
promote the use of EVs to achieve the same benefits: a reduction in local and global air pollution; less fossil fuel consumption due to a decrease in the use of ICE vehicles; and a decrease in environmental noise. However, it is necessary to remember that the increase in the use of EVs will entail a negative impact of increased electrical consumption. Although the EU promotes the generation of electricity from renewable sources, for example, through the emissions trading system (ETS), putting a price on carbon and its trading (Directive (EU), 2018), the promotion of EV and a lack of green energy could generate a rebound effect, forcing the burning of fossil fuels to generate electricity in peak hours. Therefore, investments in the energy sector in Europe should be primarily driven by environmental concerns and at urban level, and governments should try to increase renewable energy sources. Concerning the social risks and benefits, one of the threats is spending resources on charging infrastructures that are not used due to unexpected changes in the market (i.e., a preference for charging hubs or rapid expansions in EV range). Moreover, in the short-term, a CSO may not have an interest in deploying its own CSs as it could find it difficult to compete with a municipal CS networks.

The social benefits can be grouped into three categories: awareness; quality of life; and economic development. For the case of awareness, the interventions contribute to an increased environmental awareness of the public by demonstrating to them that this new mobility ecosystem is viable and feasible. People are often hesitant to accept technological innovations, especially if they entail large investments (as could be the case of having to buy an EV). By developing a robust public CS network and encouraging early adopters, which are essential actors, cities show to citizens the reliability of charging infrastructures and EVs. In terms of quality of life, the reduction of CO$_2$ and NO$_x$ gases and PM positively affect air quality and, consequently, improve the health and wellbeing of residents. In the case of Nantes Métropole and Hamburg, these benefits are expected to scale-up as the projects expand.

As has been seen throughout the paper, the adoption of EVs depends on a robust network of public CSs, which in turn, requires a considerable up-front investment with a long payback period that reduces the commercial viability for private organisations, and creates what is known as the chicken-egg dilemma. This barrier can be mitigated with a municipal investment in public CSs, which reduce the perceived risk of the venture to private sector actors. This investment, also called capex cost, must cover the acquisition of charging units, as well as the construction and installation of CSs. Obviously, as the number of EVs grow, the impact on electricity systems could become significant, and high peaks in network load will imply that cities may also need to invest in electricity-grid upgrades. Moreover, if a city keeps the operation and maintenance in-house, as is done in Hamburg, the budget cost will include both activities. The revenues produced for this type of projects are scarce. Most models rely on supranational grants (but this is a short-term solution), and on municipality taxes. In future scenarios, municipalities could obtain fees from CSOs (Nantes already receives 50% of each parking fee according to the tender agreement) and EMPs (however, these fees will be, at least in the early stages, quite low and do not represent an important source of revenue in terms of economic viability). Nevertheless, as the environmental and social benefits are substantial, and the deployment of a public CSs network clearly creates value for citizens, it is acceptable that public authorities finance these interventions at this stage.

5.2. Scale-up strategy

The development of a public CS network is a key element for
promoting the use of EVs. Once a basic network of CSs has been established, commercial attention often shifts towards developing a strategy by which to expand the network coverage. Based on the results and the analysis carried out in Sections 4 and 5.1, the authors have developed the following ten-point list (Fig. 7) that establishes the key activities needed to scale-up a public charging infrastructure network in a viable and sustainable approach in an urban ecosystem:

1. Cities should start the scale up of an EV CS network by identifying and analysing the resources they have in terms of charging infrastructure (locations, technologies, and state of maintenance) to define their own state of the art.
2. In parallel, forecast future demand for EV, and by extension future demand for public charging stations and electricity. Identifying future needs is of paramount importance for determining the appropriate size of the network at different phases of market deployment of EVs.
3. Given the foreseeable increase in energy consumption due to the consolidation of electric vehicles, updating, and resizing the network grid to ensure a continuous supply of current since the current grid lacks the necessary capacity.
4. Creation of a precise stakeholder map, identifying all the actors that could participate in this emerging market, placing special emphasis on EMPs, CPOs, and CS manufacturers. However, the list should also classify experts, research, and technology organisations, social agents, and other public administrations willing to collaborate on the deployment of EVs. The co-creation of value between multiple stakeholder domains can provide an important mechanism for aligning value within an emergent market.
5. As the capex and opex costs are considerable, define solid and viable financing and funding schemes, according to their limited resources and capacities to engage private actors.
6. Once different projects are defined, develop a decision-making methodology for prioritising and selecting those considered strategic for the development of robust network across the city.
7. Manage public procurement based on a competitive dialogue with the stakeholders previously identified to establish a public-private partnership for installing and managing public CSs.
8. Design a sequential stage approach to implement the different phases of network installation and maintenance.
9. Offer the charging service across the city, understanding and managing the entire network as a single unit that creates and delivers public value for EV owners, and allows data-based correction, as well as relevant stakeholder alignment.
10. Integrate the service into a single mobility service (Maas) solution, offering EV users tailor-made mobility planning based on their individual needs. Thus, collecting data while aligning the existing transportation infrastructure and new mobility services to optimise benefits for service providers and end consumers.

6. Conclusions

The development of a public charging infrastructure network is a key element for encouraging the adoption of EVs, and with them reducing the GHG emissions attributable to fossil fuel vehicle use and improving city environments. A prominent perceived barrier to the purchase of EVs among citizens is related to the facilities for charging EVs and their features. The implementation of public CS networks contributes to increasing the visibility of supporting infrastructure and to improving EV user experience. A visible challenge for cities and public servants relates to how best to promote the establishment and future development of a sustainable public CS network.

In view of that principle, the contribution of this paper is twofold. From an academic perspective, it contributes to the existing literature on electric mobility and introduces a holistic analysis at city level from a business perspective through the Value Creation Ecosystem (VCE) and the City Model Canvas (CMC). Both tools offer complementary information and are useful to visualise from a comprehensive perspective, how a city can offer value to the public with a long-term approach. From a managerial point of view, this paper presents the principal needs and challenges that cities are facing when deploying public CSs and identifies governance recommendations and key elements to define a sustainable and feasible policy.

From a strategic point of view, it is fundamental to offer an adequate number of CSs in the city that integrate EV user needs, such as speed, flexibility, integration, security, and parking spaces. City strategic plans should be supported by business models that promote the social benefits and environmental protections, encouraging the participation of public and private actors, both as main stakeholders and beneficiaries, as well as encouraging local business. This is the public value that justifies spending public money on this service. Municipalities can set the conditions to attract the private sector to operate in urban areas, where CSOs or EMPs are two of the most relevant players.

The expansion of the EV market goes beyond urban borders and conditions. Most vehicles are designed to be used inside and outside cities. There is a need to connect cities through electrified corridors as most people cannot afford to own different vehicles for urban and interurban travel. This means that the development of a charging station network must involve most of the political actors in metropolitan areas. An isolated city can serve as a catalyst, but it will not achieve a complete development of EVs without its neighbours. A conducive urban environment for EV adoption will help development, as cities can create a critical mass to nurture the necessary actors who will eventually take this experience and implement it in other cities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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