The Brussels Capital Region: A Case Study for Electric Vehicle Infrastructure Deployment

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1 Abstract

The Brussels Capital Region is one of the three Regions in federal Belgium and represents a highly developed urban area with a concentration of residential, administrative, commercial, educational and industrial functions.
The Government of the Brussels Capital Region is actively implementing policies to improve traffic, mobility and air quality in its area. To this effect, the use of electric and hybrid vehicles is being envisaged and a number of electric vehicles has been actually deployed. The widespread introduction of electrically powered vehicles will arise the need for suitable infrastructures to be developed.
In the framework of this paper, the mutual impact of electric vehicles and their infrastructure will be assessed. A number of infrastructure solutions which have been developed in some cities are to be assessed, and the choice of technology which is most suitable for Brussels Capital Region identified. This involves a number of aspects:

- The definition of power levels for charging, and the need for the implementation of medium or high powered facilities
- The location of public charging infrastructure, related to fleet deployment policies
- The definition of specifications for payment systems, if any, and their integration with current practices in Brussels
- The specific safety rules, regulations and standards to be adhered to

Furthermore, the actual use of the electric vehicle fleets now active in Brussels will be analysed, with special interest for the assessment of the vehicles by the users themselves. The problems associated with the operation of the vehicles, either real problems or perceived problems, will be identified in order to optimise electric vehicle use.
The paper will give an overview of the electric vehicle potential in a major European capital city, and will highlight future developments in the field.

2 **Keywords:** infrastructure

3 Introduction: The Brussels Capital Region

The Brussels Capital Region (B.C.R.) is one of the three regions that constitute the federal state of the Kingdom of Belgium. It is an urbanised area extending over 161 km^2 with a population just under one million. The Region is constituted of 19 communes, the city of Brussels proper being one of them.
Under the Belgian federal government system, the B.C.R. has its own parliament and government which is competent for matters like urban planning, environment, housing, economy, energy supply, public works, transport, public sanitation and external relations. Person-related matters like education and culture however are covered by the governments of the Flemish and French Communities.
The B.C.R. is a key centre for administrative (Belgian Federal Government, Brussels Regional Government, Flemish Regional Government, and also European institutions), educative

(several universities and higher education establishments), cultural and industrial functions. This means that it is also a major traffic centre and transport hub with a large influx of goods and passengers. The B.C.R. is served by all traffic modes: road, rail (with connections to the high speed network), air (through the nearby Zaventem airport) and water (with a sea canal allowing access to coastal vessels).
Traffic and transport problems in the B.C.R are stringent, mainly due to the large influx of commuters for Brussels' administrations. Total employment in the B.C.R. is 632000 (1991 figures, from [1]), of which 347500 commute in from outside the area. Car use is still large (73% of displacements to work) and the B.C.R. Government has devised several studies and action plans ([1], [2]), to overcome the traffic and congestion problems present. The main strongholds of these actions include, among others:

- Improvement of public transport, including the creation of a regional express rail network extending about 30 km beyond the borders of the B.C.R., in order to control car access by commuters
- Promotion of bicycle use (which is now very low in B.C.R.) through the creation of a network of bicycle routes throughout the area.
- Measures in the field of goods transport, such as the promotion of waterborne transport and the creation of distribution centres.

4 Electric vehicle developments in Brussels Capital Region

The recent development of electric road vehicle activity in the B.C.R. is related to the research activities performed at the Vrije Universiteit Brussel (VUB), which started to be active in the field since the mid 1970s. One influential development was the realisation of an automatic rent-a-car system in the framework of the "Brussels Electric Vehicle Experiment" [3]: in 1979, nine electric vehicles (built by PGE in Italy) were commissioned, with two charging and rental stations located at the VUB campuses. These vehicles have been in use until 1993 [4]. The VUB has however continued its activity in the electric vehicle field, becoming the premier centre for electric and hybrid vehicle research in Belgium. It performs research on electric vehicle drives, infrastructure and inductive charging, environmental aspects and traffic studies, simulation and standardisation.
With the emergence of road-going electric vehicles as commercial products on the Belgian market in the late 1990s, a considerable number of electric vehicles have been deployed in the B.C.R. such as a fleet of 30 Peugeot vehicles used as service vehicles by the Fire Department. Furthermore, electric vehicles (cars and small vans) are being used by services of the Regional Government, the public transport company, the Post, and by several of the communal administrations.

Furthermore, the use of electric bicycles has been covered by the E-TOUR project [5]. Electrically assisted bicycles are particularly interesting for the B.C.R. because of the hilly topography.

5 Types of charging infrastructure

5.1 Standard charging infrastructure

"Standard" charging for electric cars and small vans means using a charging power up to about 3,5 kW, corresponding to the socket-outlet of 230 V, 16A which is the most widespread in Europe.
This can be done in several modes according to relevant standards[6]:

- Mode 1 charging: this stands for the connection of the EV to the a.c. supply network utilizing standardized socket-outlets at the supply side, single-phase or three-phase, and utilizing phase(s), neutral and protective earth conductors
- Mode 2 charging makes the connection of the EV to the a.c. supply network utilizing standardized socket-outlets, single-phase or three-phase, and utilizing phase(s), neutral, and protective earth conductors together with a control pilot conductor between the EV and the plug or in-cable control box. This mode is rarely used in Europe and is not relevant in our case.
- Mode 3 charging refers to specific electric vehicle charging stations, with the direct connection of the EV to the a.c. supply network utilizing dedicated EV supply equipment. It concerns dedicated infrastructure: equipment specially designed and reserved for EV use, whether intended for public access or not. [7]

5.2 Semi-fast charging infrastructure

Semi-fast charging is defined as a power level of 7 to 10 kW, corresponding to either a single-phase 32 A outlet our a three-phase 16A outlet. This allows a doubling of the available power, with infrastructure constraints which are not too heavy or expensive.

5.3 Fast charging infrastructure

Fast charging, at high power levels up to tens of kilowatts, can be done through d.c.or a.c. connection.
The d.c. fast charging station is known as “Mode 4” charging. It makes use of a transformer and rectifier which are ground-based. These charging stations tend to be heavy and expensive. Vehicles fitted with a.c. drives may have inverters which are able to charge the battery at high power when connected to an a.c. supply. This allows fast charging under Mode 3, using much lighter fixed infrastructures. Furthermore, it allows the electric vehicles to be included in peak-shaving strategies.

5.4 Inductive charging

Systems using inductive charging have been extensively studied by the VUB [8]. The inductive charging systems can be either manual connected (paddle type) or with automated docking. The manual systems are less likely to be used as a standard solution in the B.C.R. since this equipment is not widespread on vehicles manufactured and marketed in Europe. Automatic systems could prove interesting for captive fleets in certain applications like automatic rent-a-car systems or taxi fleets, which may benefit from the opportunity to access opportunity charging without the fuss of a cable connection. Inductive charging, particularly at high power levels is here a much more efficient and elegant solution than battery exchange which has been proposed for some of these applications.

6 Overview of existing infrastructures

6.1 Mode 1 charging

Up to now, electric vehicle charging has been done mostly in Mode 1. This mode allows normal charging using standard power outlets, which are readily available.
Mode 1 charging, due to its simplicity and low cost, is likely to remain the preferred mode for all charging operations taking place in controlled environments like private or corporate

garages. For dedicated infrastructure aimed at the public thoroughfare however, more extensive safety and security measures are required as in Mode 3.
It is however advisable that the accessories used for electric vehicle charged are of the "industrial" type, according on IEC 60309-2 [9]. These are of a heavier build then standard "domestic" plugs and more suitable for harsh environments, repeated disconnection under load and prolonged operation at high current rates.

However, Mode 1 charging has raised a number of safety concerns: its safe use depends on the presence of a residual current device (RCD) on the supply side. The installation of such device is now enforced by national codes in most countries, including Belgium; however, many older installations continue to exist without RCD, or even without protective earth conductor connection. In such cases, hazardous conditions may occur after a fault. Thus, without RCD, mode 1 charging is not permissible.

6.2 Mode 3 charging

.6.2.1 Generalities – Control pilot

6.3 Mode 3 charging refers to specific electric vehicle charging stations, with the direct connection of the EV to the a.c. supply network utilizing dedicated EV supply equipment where the control pilot conductor extends to equipment permanently connected to the a.c. supply. It concerns dedicated infrastructure: equipment specially designed and reserved for EV use, whether intended for public access or not.

6.4 The control pilot is a device which controls the integrity of the protective (earth) conductor (by adding a control pilot conductor which forms a loop with the protective earth conductor), and which is able to perform additional safety functions, such as ensuring the socket outlet is dead when no vehicle is present, as well as basic communication functions. This is particularly interesting for charging stations located in public locations.

The concept of control pilot is described in European and international standards [7].

.6.4.1 Examples: the French public charging network

In France, an extensive network of public charging stations has been established by the electricity company "Electricité de France" (EDF) [10] The stations are present in all major cities in France, the strongest development of course is in cities with an extensive EV activity like Paris or La Rochelle. In the French capital, there are over 200 charging points available at 51 locations spread throughout the city, located in underground parkings, commercial parking lots and on the street.
All these stations are fitted with control pilot protection and accept electric vehicles as they are offered on the French market. The plugs used, which remain compatible with domestic socket-outlets to allow home charging (which is Mode 1 of course), are locked during the charge to prevent unauthorised removal.
Access is controlled through chipcards (see infra) which can be acquired from EDF.
Developments for allowing semi-fast charging are also be developed in France.

Figure 1: French –type public charging station with two outlets. The control panel and chipcard reader are at the rear; the station can control additional outlets.

.6.4.2 Examples: the Swiss public charging network

Switzerland has a large fleet of electric vehicles in use by private persons. To give EV users a greater mobility and range, a large network of public charging points have been developed under the name "Park & Charge" [11]. This network aims to make use of the existing electric network without making the high investment costs of installing highly sophisticated charging stations. The access is based on a membership subscription system. Hundreds of charging points are available throughout Switzerland, with a particular high concentration in pilot EV areas like Mendrisio and the Ticino canton. They are deployed by both municipalities, electric utilities, garages, restaurants, and others.

The basic Park & Charge station consists of one or more standard socket-outlets located in a cabinet accessible with a special key given to all members of the scheme. It is thus basically Mode 1 with mechanical protection through the key. However, a new type is now being proposed, offering Mode 3 operation with a modified IEC 60309-2 plug, which allows semi-fast charging at 32 A. This system is geared to the so-called "booster" chargers which allow to double the charging power (and thus decrease charging time), while the normal charging at 16 A remains possible (e.g. at the home garage).

Similar charge networks, also under the "Park & Charge" banner are being developed in Austria and Germany.

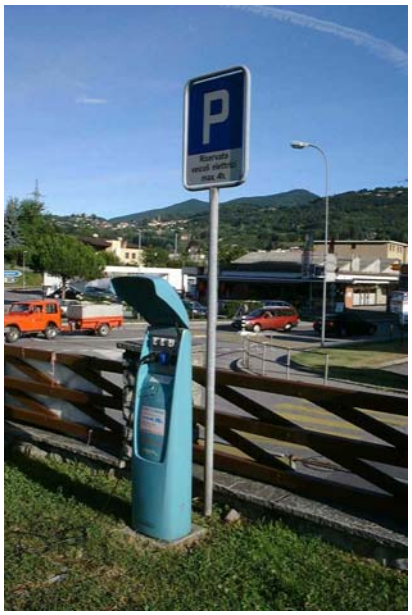

Figure 2: Swiss public charging station in Mendrisio

6.5 Mode 4 charging

In Mode 4 (the indirect connection of the EV to the a.c. supply network utilising an off-board charger), the vehicle is charged with a d.c. current provided by an off-board charger. Vehicles in captive areas like industrial vehicles are mostly charged with off-board chargers; for road-going vehicles, this solution is most often used for fast charging stations which require a very heavy infrastructure.

Public fast-charge infrastructures have been developed in France by EDF. In Paris, there are 5 such stations, mostly located at petrol stations. There are accessible with the same chipcards as the normal charging stations; however, their rates are more expensive. Practical experience has shown that they are nearly only used for "emergency" charging.

Even if their actual use is fairly low, the Mode 4 fast charging stations answer to a need: their mere presence can serve as a psychological "insurance" for EV drivers, giving them the confidence to exploit the whole range of their vehicle.

Similar infrastructures have been developed in other countries; figure 3 shows an example from Sweden.

One additional application of Mode 4 charging are of course heavy vehicles like city buses (example: the "Montmartrebus" in Paris), which have access to dedicated charging stations at their termini.

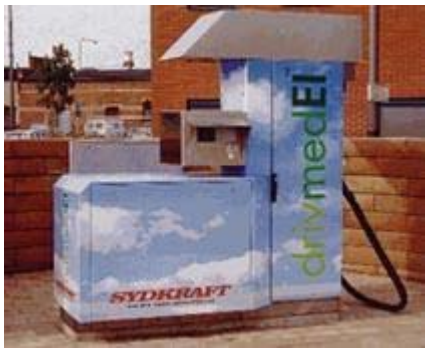

Figure 3: Fast charging station

6.6 Payment aspects

Payment for the use of electric vehicle infrastructure can be done in different ways:

- Paying for the electricity
- Paying for the time the infrastructure is used
- Paying a lump sum

Payment for electricity consumed necessitates the use of a suitable energy metering device. One has however to take into account that the actual value of the energy used is quite low: for one hour charge, the typical energy used will be about 3,5 kW, the value of which is less than € 0,50. This is much less than the usual hourly rates for parking in cities. For this reason, time-based payment is more advised: on one hand, a time metering device is much simpler and cheaper to implement; on the other hand, charging the time used will discourage users to leave a car connected for a long time once it is fully charged, thus unnecessarily occupying the outlet and barring its use by others.

Paying a lump sum for the charge, without actual measurement of time or energy consumption, is the least sophisticated system. It is being used for example in the "Park & Charge" scheme in Switzerland, which encompasses also numerous Mode 1 charging points located at hotels, restaurants, and the like. Access to this system is based on a membership scheme, with a lump sum to be payed to the Park & Charge organisation for every day the system is actually used.

The actual payment can be done in several ways:

- Using coins. This solution is simple, but has a lot of drawbacks: need for physical collection of coins, risk for theft and vandalism.
- Using chipcards. These devices are gaining popularity as payment devices.

The French public charging network uses proprietary chipcards which are sold by EDF. These are debited according to the time the infrastructure is occupied, with special rates possible during the night.

7 Which choice for Brussels Capital Region?

7.1 Generalities

At the moment, there is no publicly accessible electric vehicle charging infrastructure in the B.C.R., except from a demonstration charging station (of EDF type) at the V.U.B. laboratories. Policies to promote electric vehicle use in Brussels will establish the need for public charging

infrastructure, not only for actually charging the vehicles, but also because the presence of such infrastructures as part of the urban landscape is a key element in making the electric vehicle known to the general public and in highlighting the environmental policies of the local authorities.
The choice of an infrastructure remaining open for the moment, the experiences in other countries can be considered to find the optimal solution for the needs of the B.C.R.

7.2 Fleet vehicles

For fleet vehicles, which can be charged at their depots, the choice of Mode 1 charging (preferably using IEC 60309-2 accessories, and with suitable protection measures on the supply side) remains the most sensible one. However, vehicles which are used more intensively may benefit from the availability of semi-fast charging or even fast charging. Since these infrastructures are used in a controlled environment (private depot), they don't need the same access control or payment technologies then public ones, and thus can be realised at reduced cost.

7.3 Public infrastructure

Charging infrastructure which is accessible to the public has to be Mode 3 in order to ensure optimum safety. Most electric vehicles on the market are already compatible with Mode 3 charging stations.
The type of payment for the charging can be organised in different ways. Charging stations which are situated in controlled-access environments such as parking houses or multi-storey car parks (which are quite plentiful in Brussels) may refrain from a payment system since the cost for the energy can easily be included within the parking fee (it is, as we have seen, lower anyway).
On-street charging stations will need some kind of payment system. As for the specific situation in Brussels, the most interesting technology seems to be to make use of the "Proton" card. Proton is a rechargeable electronic purse, created by Banksys, Belgium, in 1994. The chip-card Proton makes it easy for small traders to have access to an electronic payment system, which is in general much safer than cash payments.
The use of Proton is widespread in Belgium: today every one of the 8 million cash cards in Belgium are accompanied by the Proton-system. The technology is also used in 24 different countries; world-wide 34,5 million rechargeable cards circulate, which makes Proton the international standard in Smart Cards. The system part (Proton card reader) is a simple, reliable and affordable device.
Of course, local authorities can futher promote electric vehicle use by offering the energy for free. However, a user registration and payment system may ensure a more sensible use pattern (e.g. not occupying the charging station for a prolonged period after full charge).

The forthcoming appearance of the market of vehicles fitted with "booster" charges allowing semi-fast charge makes it desirable to equip the Mode 3 charging stations with suitable outlets for 32 A charge.

Furthermore, a limited number of fast charging stations (mostly for emergency charging) are to be built at suitable locations. They are to be accessed with Proton payment at a special rate.

7.4 Localisation of the public infrastructure

A number of locations to implant EV supply equipment in the B.C.R. are to be proposed as a policy support measure. Figure 4 gives an overview of key activity areas in the Region which may serve as locations for an initial network of EV charging stations. These locations are activity hubs where a high volume of electric vehicle traffic may be expected.

A. The *city centre* or downtown area, where the main activity poles are tourism, shopping, entertainment, government offices. This area has several multi-storey car parks where reserved places for EV (with charging infrastructures) are to be implanted. An on-street charging station could be beneficially built on a high-visibility location as a policy dissemination measure.

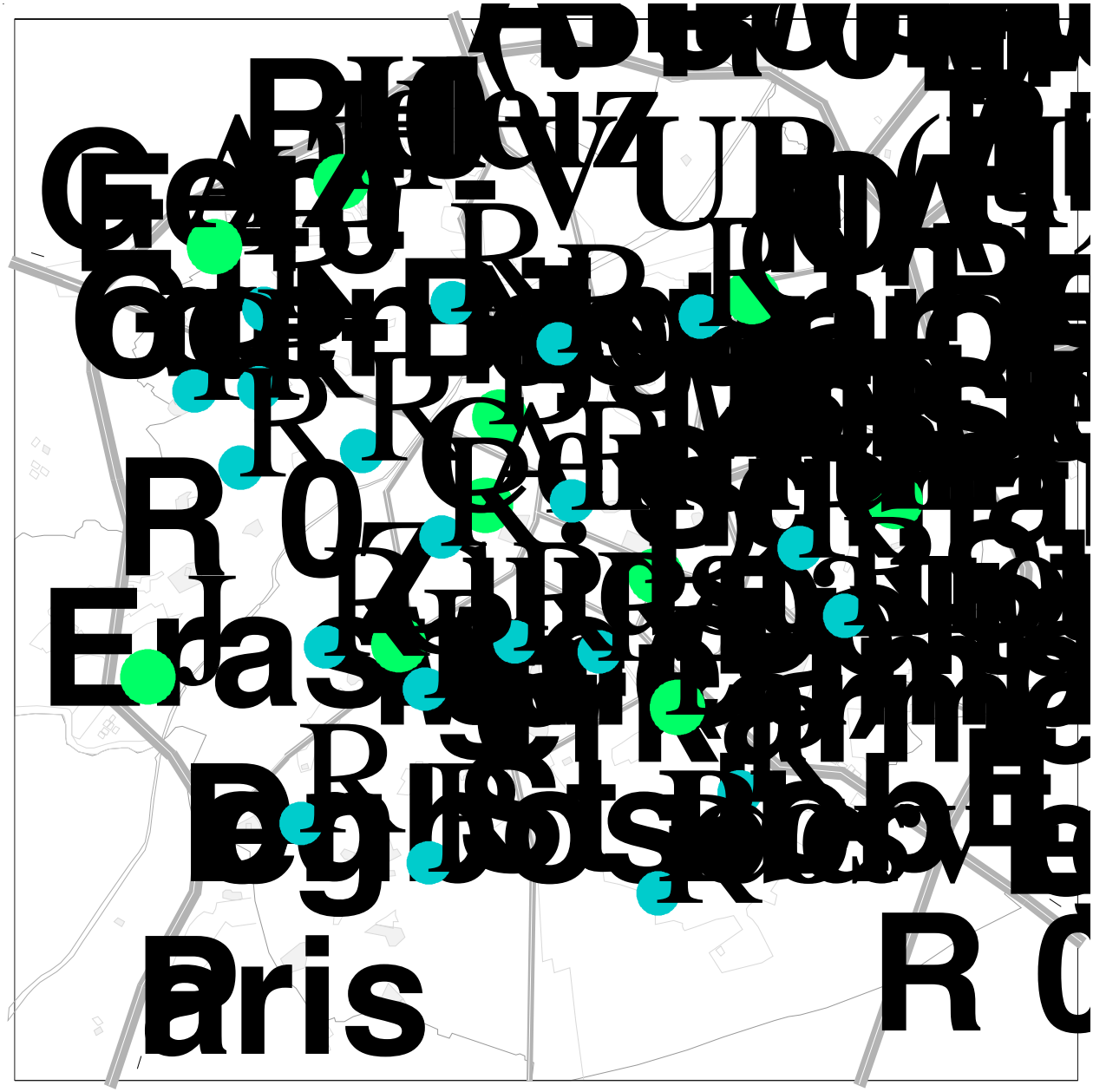

Figure 4: Key locations for charging infrastructure in the B.C.R.

B. The *North station area*: regional administration, business offices and a key transport hub.
C. The *South station area*: the main railway station in Brussels, on the high-speed network
D. The *European quarter*: seats of the European institutions, and high-visibility area for policy demonstration
E. The *South-east* quarter, with its universities and business centres
F. The *Woluwe* area, with a concentration of new business developments and an academic hospital
G. The *North-east* area, in the direction of the airport
H. The *Heizel*, a focal point for leisure activities and the exhibition centre
I. The *West* , with its medical campus and transit functions close to the main ring road
J. The *South-west* area

R. Locations for *residential* charging infrastructure (see below)

These ten locations are to be fitted with Mode 3 charging stations; a typical configuration would be five outlets available per location. The forecast extension of the number of electric vehicles in use will make it necessary to tighten the mesh by adding new stations on locations where they are needed.

Existing car parks (including car parks associated with superstores and shopping centres) are particularly suitable to implement EV supply equipment without the extra cost cost or the special planning issues which are associated with the implementing of such equipment on the public throughfare.

The exact locations of the infrastructures to be implemented in the zones described above are to be determined taking into account the following local and global factors:

- The availability and locations of existing structures like multi-storey car parks which may host charging stations
- The interaction with other transport modes and the intermodality. This is particularly interesting for applications like automatic rent-a-car or car-sharing systems, which may be using the infrastructure
- Local planning issues, where on-street infrastructures may be developed in areas with reserved access for electric vehicles, thus highlighting their environmental benefits

For the deployment of fast charging infrastructures, the peripheric locations are particularly suited, since one of the likely needs for fast charging is when the EVs are used for trips crossing the regional borders.

7.5 Residential charging infrastructure

A large number of private car users in Brussels uses their vehicle mostly for urban and local displacements and could thus be eligible to switch to EVs. The oncoming availability of hybrid EVs fitted with range extenders will make the electric option even more attractive to the private user, since it makes displacements like the traditional weekend trip to the sea feasible by EV.
Residents which have access to private garage or a reserved parking place can easily provide a Mode 1 outlet to charge their vehicle. There are however a large number of residential neighbourhoods in Brussels (particularly those preceding the era of mass car ownership), where there are few garages available.
Public charging infrastructure should be provided for EV owners living in such areas.

Suitable locations for these stations are the municipal centres of the 19 communes that constitute the territory of the B.C.R. These locations are within the residential areas and are also shown on figure 4 (including one in the former municipal centre of Laken which is part of Brussels city).
These infrastructures could be compatible with and integrated in the same network cited above and are in fact one typical area for new developments in the field. Residents using their "local" charging station could benefit from preferential rates for overnight charging.

8 Backgrounds and Acknowledgements

The research activities underlying to this paper have been performed within a research project performed by the Vrije Universiteit Brussel, Department Electrical Engineering and Energy Technology, on behalf of the Brussels Capital Region.
The full report of this project, which will include a thorough assessment of the experiences of current electric vehicle users in the B.C.R., will be finished by the end of 2001.

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