Nantes | Hamburg | Helsinki



mySMARTLife

Deliverable due date: M36 – November 2019

D2.13 – Monitoring solutions for EV uptake

WP2, Task 2.7

# Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

| | | | |
|---|---|---|---|
| Project Acronym | mySMARTLife | | |
| Project Title | **Transition of EU cities towards a new concept of Smart Life and Economy** | | |
| Project Duration | 1st December 2016 – 30th November 2021 (60 Months) | | |
| Deliverable | D2.13 – Monitoring solutions for EV uptake | | |
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| Due date | 30/11/2019 | | |
| Work Package | WP2 | | |
| Lead beneficiary | CER | | |
| Contributing beneficiary(ies) | NAN | | |
| Task description | Subtask 2.7.2: Monitoring solutions (EV and charging point). A solution for the Installation and monitoring of 10-15 recharging stations at terminus and main stops (Electric bus); 49 Slow recharging stations for electric vehicles (EV); 16 Accelerated recharging stations for EV (enclosed parking lots); 200 secured bike plugs for e-bikes will be developed. In this subtask, focus on the connection of EV charging stations to the urban platform and aggregation with other mobility data and the development of some use cases. NAN and ENG will collaborate in this EV charging stations uptake. | | |
| **Date** | **Version** | **Author** | **Comment** |
| 20/05/2019 | 1.0 | M. Bossard (CER)<br>P. Nouaille (CER) | Section 4: Draft version on recharging points |
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# Table of Content



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# Table of Figures



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# Table of Tables



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# 1. Executive Summary

This deliverable aims at presenting three main deployments led by Nantes Métropole on its territory in terms of electro-mobility within the EU-funded "mySMARTLife" project:

- The first project called "eBusway" deals with the deployment of twenty-two fully-electric 24-meter-long buses on a specific line of the public transportation system;
- The second one is about the installation of recharging stations for Electric Vehicles (EV) including e-cars and e-bikes, in parking lots of Nantes city centre;
- Last one is an autonomous shuttle experiment with a full-electric vehicle embarking up to 11 passengers.

This deliverable reports on the operational context of these actions, their objectives and the technical aspects of the experiments (equipment characteristics, choices in terms of technology, functionalities, and technical constraints related to the deployment). It also presents the key performance indicators that will be used for the evaluation of each action.

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# 2. Introduction

## 2.1 Purpose and target group

Nantes Métropole[1] is a public establishment that is in charge of mobility (among other subjects) on the French city of Nantes and on twenty-three surrounding municipalities. Nantes Métropole has committed to organize the development of the transportation system of Greater Nantes and to encourage a more sustainable mobility. Its commitment is formalized in its Urban Mobility Planning (for French "Plan de Déplacements Urbains" or PDU for short) from years 2010-2015 approved in 2011 and then its new version on the period 2018-2027 approved on December 7, 2018. Nantes Métropole aims at reaching a better equilibrium between cars (including carpooling), two-wheelers, public transport and active modes (pedestrians, cyclists) with four main objectives:

- Preserving the environment and public health by changing the behaviours in terms of mobility to reduce the emissions of greenhouse effect gases (GHG) of 50% by 2030 compared to 2003;
- Promoting short-distance trips (say less than 3 kilometres) and active modes, in particular walking and cycling;
- Optimizing logistics in urban areas and promoting the use of the less pollutant energy;
- Guaranteeing a mobility for all: setting dedicated services for people in needs.

In the framework of EU-funded "mySMARTLife" project in which it is involved, Nantes Métropole decided to promote electro-mobility actions that go in the directions prescribed by its Urban Mobility Plan. It is included:

- The deployment of full-electric 24-meter-long buses called "eBusway";
- The installation of recharging stations for Electric Vehicles (both for individual e-cars and e-bikes);
- The experiment of an autonomous shuttle with a full-electric vehicle.

For each of these three actions, the report details the stakes faced by Nantes Métropole and the pursued objectives. It also gives details about the technical choices done by Nantes Métropole as well as the constraints they had to deal with during the deployment of these actions. Thus, this document allows local authorities that could be interested in similar projects, to benefit from a first feedback from Nantes Métropole about the promotion of electro-mobility.

[1] https://www.nantesmetropole.fr

## 2.2 Contributions of partners

The following table (see Table 1) depicts the main contributions from participant partners in the development of this deliverable.

**Table 1: Contribution of partners**

| Participant short name | Contributions |
|---|---|
| CER | Overall content and redaction of all the sections of the deliverable |
| NAN | Leader of the actions<br>Providing of information and data<br>General review of the content of the deliverable |
| TEC | General review of the content of the deliverable |

## 2.3 Relation to other activities in the project

The following table (see Table 2) depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

**Table 2: Relations with the other activities in the project**

| Deliverable Number | Contributions |
|---|---|
| D2.1 | Baseline report of Nantes demonstration area |
| D5.1 | Integrated evaluation procedure |
| D5.2 | Definition of the data sets and requirements |
| D5.3 | Monitoring programs and deployment in the three lighthouse cities |
| D2.8 | Development of improved services in Nantes Urban Platform |

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# 3. "eBusway": electric buses deployment in Nantes

This section explains and describes the "eBusway" project deployed in Nantes in 2019. This project covers the rollout of twenty-two 24–meter-long electric buses as a means of public transport in the South-eastern part of Nantes's metropolitan area.

## 3.1 Project origins

The description of the project starts by explaining how the existing bus line works and by listing its performance as well as its shortages, which led to the elaboration of the project. We also give a timeline of the political process, which gave birth to the "eBusway".

### 3.1.1 Nantes public transport system: focus on line 4

#### 3.1.1.1 Overview of Nantes Métropole public transport network

In Nantes's agglomeration, the public transport system is under the responsibility of Nantes Métropole. As a reminder, Nantes Métropole (that could be translated as "Greater Nantes") is a Public Establishment for Intercommunal Cooperation, created in 2001 and covering twenty-four towns encompassing and around the city of Nantes. By delegation, Nantes Métropole chose the SEMITAN to build, renovate, operate and make the public transport network reliable. SEMITAN is standing for the acronym of the French name "Société d'Economie Mixte des Transports en commun de l'Agglomération Nantaise". It is a mixed economy Company. The SEMITAN capital is hold at 65% by public funds (Nantes Métropole) and at 35% by private capitals (Transdev, banks and associations). It employs around 1,900 people including 1,200 drivers.
It is noteworthy that "TAN" is the trademark used for Nantes Métropole public transport network.

Historically, Nantes has been a pioneering city in France in terms of public transportation system: for instance, Nantes started using omnibus with horses in 1826. It also introduced the first tramway functioning with compressed air in 1876. Nantes was also the first city to reinstall modern tramway lines in 1985. As we will describe it, the e-Busway deployment is a world premiere as it is the very first 24-meter-long fully electric bus.

In 2019, the public transport network in Nantes agglomeration is structured around four major lines: three tramway lines, numbered 1 to 3, and the Busway line 4 (see Figure 1). These lines cover around 50 kilometres. In 2017, 70.6 millions of passengers travelled in the Nantes tramways.
On June 7, 2019, elected officials from Nantes Métropole announced that three new tramway lines (lines 6 to 8) would be created. These lines will serve the future Nantes hospital in construction on Ile de Nantes. The officials also announced that the Chronobus (bus rapid transit) line 5 would be transformed into a Busway line 5 by Spring 2020.

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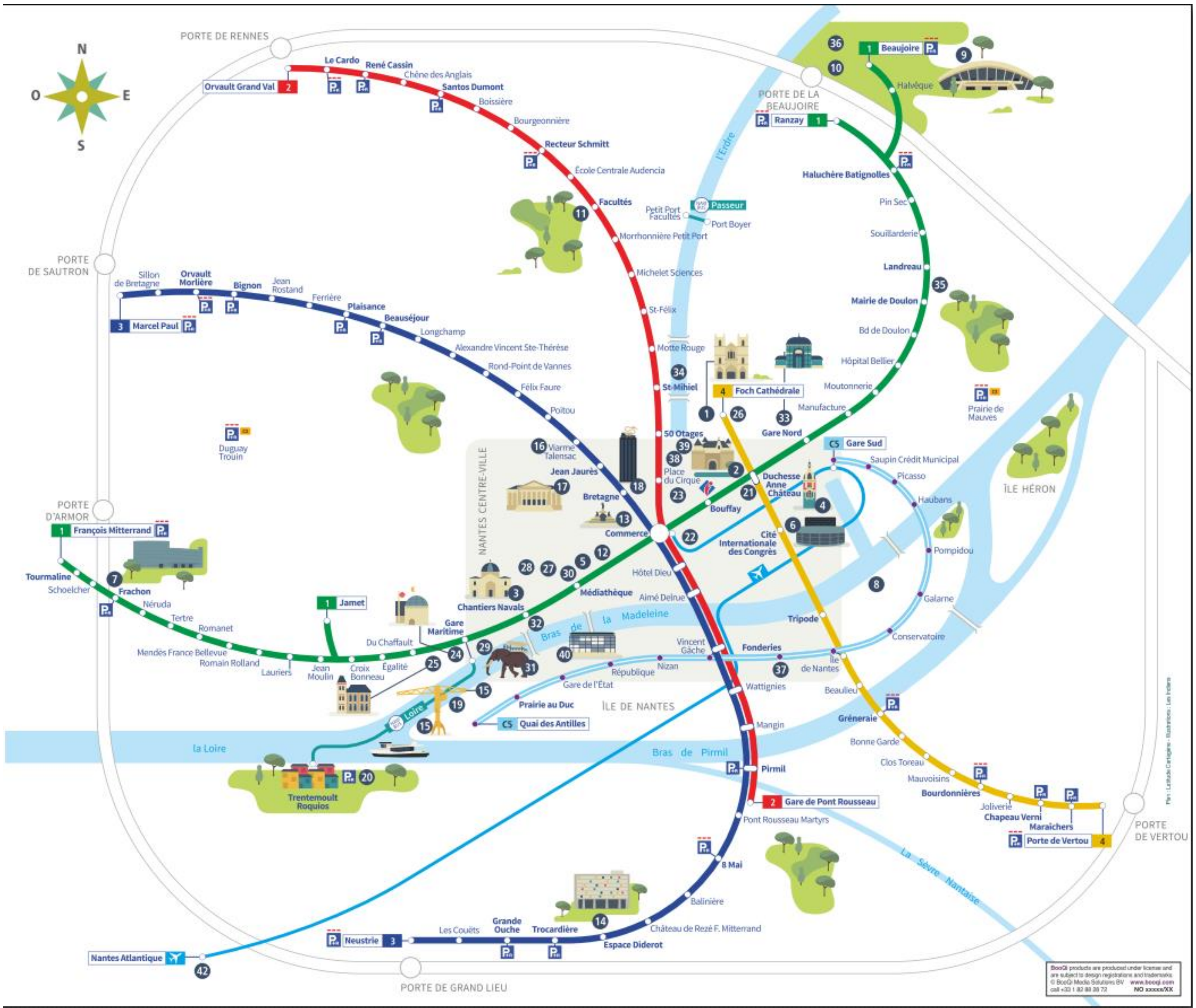


**Figure 1: Simplified view of the main public transport network in Nantes agglomeration (source: tan.fr)**

### 3.1.1.2 Busway line 4: presentation

The Busway line 4 is a bus line with a high level of service (bus rapid transit), covering 7 kilometres, most of which are on dedicated right-of-way. This is the reason why the line is named “Busway”. The Busway line 4 has been in operation in Nantes agglomeration since November 6th, 2006. It was one of the first line of this type in France. This type of bus with high level of service was inspired by the Northern American Bus Rapid Transit system, using reserved lanes on highways.

Busway line 4 connects three municipalities in the South-eastern part of the agglomeration: Vertou, Saint-Sébastien-sur-Loire and Nantes. There are 15 stations from Place Maréchal Foch in the city centre of Nantes to Porte de Vertou, in the South-eastern outskirts of Nantes (see Figure 2). It interconnects with tramway line 1 at Duchesse Anne

Château station. There is an average distance of 543 meters between two consecutive stations. The shortest distance between two stations is 265 meters (Ile de Nantes – Beaulieu) while the longest is 675 meters long (between Tripode and Cité Internationale des Congrès). The Busway path is mainly flat.
Porte de Vertou station is located close to an off-ramp of the Nantes ring road, while Place Maréchal Foch is at the heart of Nantes historic city. The travel time between both terminus stations is approximately of 20 minutes. Six park & ride (P+R) facilities have been built along the line to encourage passengers to use public transport. The buses drive at an average commercial speed of 21 km/h.

Sometimes, events such as demonstrations, road works and so on can disturb the operations on the bus network stretch located at the city centre (from Foch-Cathédrale to Cité Internationale des Congrès). In such cases, the buses are either partially rerouted or the terminus station is temporary set up at Cité Internationale des Congrès.

The bus service starts at 4:45 am in the morning and stops at 00:45 am (weekdays and Sundays) or 2:45 am (Saturday evening). In terms of daily attendance, the line works as a typical radial public transport urban line meaning that there are mainly two peak periods:

- at the morning peak hour (approximately from 7:00 am to 8:40 am), commuters go from the outskirts to the city centre for work or school,
- at the evening peak hour (approx. from 4:00 pm to 6:40 pm), they go back home from the centre to the suburbs.

There is also an attendance increase at the midday period (11:00 am to 1:00 pm).


**Figure 2: Schematic representation of bus line 4 (Source: SEMITAN)**

#### 3.1.1.3 Busway line 4: history of the project

Originally, at the beginning of 2000's, the project was to make an extension of tramway line 3 up to make it reach the city of Vertou and to connect to the existing tramway line 2 at Pirmil station (bridge over Loire River, close to Ile de Nantes, Southwest part of Nantes – see Figure 1). This initial project was turned down because of insufficient traffic forecasts and the financial disengagement from the French State while being costly.

At the time, Mayor Jean-Marc Ayrault asked for an alternative with a limited cost and the same level of service as a tramway. This led to the idea of the "Busway". Nantes Métropole, Transdev and the SEMITAN jointly developed this concept of Bus Rapid Transit. It combines:

- A high level of service almost similar to the one provided by tramways, thanks to the dedicated lanes, the high frequency and the high capacity of the operating buses;
- The flexibility and moderated costs of buses compared to tramways since railways or electrical cables are not needed.

The Busway project in Nantes was officially announced in 2002. The concept named "Busway" was signed in March 2005 between Nantes Métropole, Transdev and SEMITAN and the civil works started the same year. Operations started in November 2006. It was one of the very first bus with a high level of service in France, with TEOR in Rouen (since 2001). Several French cities like Lyon (trolleybus on lines C1 starting in 2006), Metz (since 2013), Strasbourg (since 2013) or Nancy (since 2013) and many others were inspired afterwards.

#### 3.1.1.4 Attendance on Busway line 4

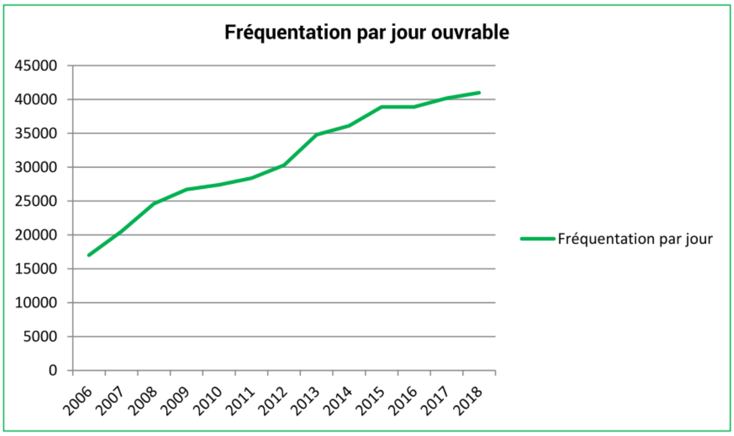


**Figure 3: Chart of the attendance in passengers per day on Busway line 4 (source: SEMITAN)**

Its high level of service and its transportation capacity have enabled it to attract a growing clientele and to contribute to the modal shift policy of the Nantes agglomeration. In addition, the South-eastern part of Nantes agglomeration has known a strong population growth in recent years. After only two years, it reached its goal of 25,000 travellers per day. Its initial conception allowed it to adapt gradually to the growth in attendance: from 23,600 travellers per day in 2007, it rose to 40,200 travellers per day in 2017. This represents 9.5 million of passengers per year.

#### 3.1.1.5 Description of the buses on line 4

Today the fleet is composed of twenty-three (23) Mercedes-Benz “O 530 Citaro G CNG” buses (see Figure 4). These buses are 18-meters long articulated vehicles, with three axles and four sliding doors, which can at top capacity host 110 passengers. The driver is isolated from the rest of the bus in a separate cabin. This bus model is an articulated version based on the conventional single-decker rigid Mercedes-Benz “O 530 Citaro” bus. Compared to classical O 530 Citaro G buses, this high-end version offers the fairing of the wheels and the roof of the bus where the CNG reservoirs are located. Similar buses are operating in the French cities of Amiens, Saint-Etienne Dijon and Strasbourg. The “CNG” acronym stands for Compressed Natural Gas, meaning that these bus engines are powered by natural gas. The “M447 hLAG” 326 horsepower engines from Mercedes-Benz comply with the EURO-IV emission levels. In average, the buses operating on Busway line 4 are 12 years old. The SEMITAN bought the first new 20 buses new in 2006. The three last buses built in 2007 were bought used in 2012 from the city of Dijon. In average, each Busway has travelled around 41,000 km per year (with a max 400 km per day, corresponding to a maximum of 25 round trips per day) that to say more than 500,000 km from 2006 to 2018.

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**Figure 4: Picture of a Mercedes-Benz "O 530 Citaro G CNG" bus operating on Busway line 4**

**(Credit: Jean-Louis Zimmermann, Flickr)**

Interestingly, Nantes Métropole launched a first call for tenders in 2002, concerning 18 or 24-meter-long hybrid buses for its Busway line. At the time, only two offers were made:

- On one hand, there was the Phileas model by APTS consortium (standing for Advanced Public Transport Systems B.V. mainly owned by the Belgian manufacturer VDL) that was tested and deployed in Eindhoven (Netherlands) since 2001 and then deployed in other cities such as the French city of Douai. However, this 24-meter-long bus model suffered of homologation issues due to its complex guided driving mode.
- On the other hand, there was the Cristalis model by French-Italian Irisbus (now Iveco Bus) company. This 18-meter-long bus exists in different motorizations: for instance, it is used as trolleybus in Lyon since the beginning of 2000's. However, its diesel-electric hybrid version has the drawback of a high consumption of energy compared to trolleybus. It is noteworthy that ten diesel-electric Irisbus "Civis", a close version of the Cristalis model differentiating only by its optical guiding, were deployed from 2003 to 2010 in Las Vegas, Nevada.

#### 3.1.1.6 Busway line 4: current limitations

This line has faced a dramatic increase in attendance and therefore ended up in hitting its maximal threshold very quickly. During peak hours, 19 out of 23 buses are being deployed on the line. It has been also decided to increase the frequency from a bus every 4 minutes to a bus every 2 minutes 45. This frequency is a maximal barrier because of the traffic signal cycles and the dwell time (i.e. the time required for up-and-downs) at each station, including the

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terminus stations. However, these solutions quickly showed their limits. Therefore, passengers and drivers experiment less comfort during their travels due to overcrowded vehicles. The operation is also perturbed with bus bunching phenomenon and the travel time increase. Punctuality and regularity worsen due to this saturation.
This led to the operators searching for new solutions for the line to remain attractive while satisfying the increasing demand. The "e-Busway" project consists on launching a new stage in the evolution of the line by acquiring 24-meter-long vehicles allowing the accommodation of approximately 150 passengers, which constitutes an increase of the transport potential of 35% at peak hours.
It is noteworthy that the 23 Mercedes-Benz “O 530 Citaro G CNG” buses will be reassigned to the future Busway line 5 (which used to be a Chronobus line).

### 3.1.2 eBusway project timeline

Below is a brief timeline of the eBusway project:

- From 2012 to 2015: technical benchmark of (existing and planned) bus solutions on the market;
- July 2015: presentation of a technical note dealing with a comparison of market solutions, to political representatives including Mrs. Johanna ROLLAND, Mayor of the City of Nantes and president of Nantes Métropole. The details of this note are provided in the next subsection (Section 3.1.3).
- December 2015: political validation for the kick-off of “e-Busway” project;
- From 2016 to the first semester of 2018: infrastructure studies;
- July 2016 - June 2017: consulting and choice of the rolling stock and of the recharging system;
- December 2018: delivery of the first e-Busway vehicle in Nantes;
- From January to November 2019: road works including charging stations;
- From May to November 2019: deliver of the twenty-one remaining e-Busway vehicles;
- Autumn 2019: roll-out of the twenty-two e-Busway vehicles on bus line 4.

On January 24, 2017, the President of Nantes Métropole Johanna Rolland announced the extension of the line. It would go beyond the ring road, and continue after the Porte de Vertou station for a distance of 1 kilometre up to the Clouzeaux district in Vertou. There, a new technical warehouse would be built to accommodate the twenty-two new electric buses.

In an announcement made on June 7, 2019, independently of “mySMARTLife” project, Nantes Métropole’s officials communicated on the extension of Busway line 4 outside of the ring road, from Porte de Vertou station up to the centre of Vertou by 2027. The bus line will be 4.5 km longer and aims at serving the future high school in Vertou, scheduled for 2027.

### 3.1.3 Technical directions: towards electromobility

Through this “eBusway” project, Nantes Métropole faced two challenges:

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1. The increase of the capacity to satisfy the ever-growing demand;
2. The maintenance of its commitment together with SEMITAN in terms of energy transition.

It has been observed that with over 40,000 travellers a day, there is an important lack in the number of passengers that can be taken on-board on the Busway line 4. Therefore, Nantes Métropole and SEMITAN's Departments in charge of mobility suggested the purchase of 24-meter-long buses to replace the 18-meter-long ones, which would be used on other lines. That way, the hosting capacity of Busway line 4 would increase by 35%, considering the 18-meter buses can host 110 travellers per vehicle, while the 24-meter ones can host 150 people per vehicle.

#### 3.1.3.1 2015 market study

Several options were looked upon for the type of motorization, which would be used for the vehicles. Since the end of the nineties, Nantes Métropole has been choosing Compressed Natural Gas in every bus purchase, except for six 18-meter-long diesel-electric hybrid buses to try this kind of technology. However, it ended up being an additional expense for Nantes Métropole, as on a 15-year period of time, each vehicle cost about 200k€ more than a similar 18-meter CNG bus. Moreover, Nantes Métropole strongly wanted to stop using diesel.

CNG-electric hybrid vehicles were considered. Only the Belgian bus manufacturer Van Hool produces 24-meter-long hybrid CNG-electric vehicles. These buses have been circulating since 2014 in Malmö (Sweden) and Bergen (Norway). The main positive point of these buses is their low CO2 and NOX emissions, which fit the Euro VI emission laws applicable since January 1st, 2014. Here are their characteristics:

- Maximum lifespan of 20 years,
- Estimated price of 950k€ ex-Tax per vehicle, that is to say 22.8M€ inclusive of VAT for 20 buses,
- Consumption comparable to current CNG buses (with less consumption due to the fact that it is hybrid, but compensated by the over-consumption due to the gain in capacity),
- Higher upkeep cost caused by the bi-articulation and the use of batteries.

Another possible alternative was fully electric buses chargeable along the line. As it is discussed later (see in particular Section 3.2.2.2), the solution of a bus recharged during the night was disregarded because of the loss of capacity due to the volume and weight of the embarked batteries.

In 2015, there did not exist any system with a daylong autonomy, hence the need to have the possibility to charge the buses both at terminus stations and along the line. So far, only two systems of this kind existed in 2015 on either a demonstrator or commercial scale:

- Hess experiment with TOSA system provided by ABB company, which provide a recharge through an automated articulated arm which connects on a totem;
- Primove by Bombardier, which charges the vehicle by means of floor induction.

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The characteristics of these systems are as the following:

- Maximum 30-year lifespan (Hess experiment)
- Estimated price of 1.31M€ ex-Tax per vehicle, that is to say 31.5M€ inclusive of VAT for 20 buses
- 10M€ inclusive of VAT for all infrastructure installations at terminus stations and along the line
- Consumption savings unsure: better output of the electric engines compared to gas ones, but the evolution is so far unpredictable
- Upkeep fees: more significant than CNG engines due to the batteries, but lower than CNG-electric hybrid vehicles.

In addition to the capacity increase with longer vehicles, these new buses will maintain Nantes Métropole and SEMITAN's commitment to energy transition by being electric. Their batteries will be rechargeable during operations. This innovative technology allows an exclusive use of electrical energy like a tramway. It will lead to an estimated 1300-tons reduction in terms of CO2 emission per year, which is the current overall annual emission for the CNG buses based on the travelled distance.

Following its market study, Nantes Métropole decided to launch a call for bids for 24-meter-long buses but with no strong restrictions on the motorization. The only requirements were:

1. The technical solution should not imply constraints on the operations (for instance, longer stop times at stations or shorter daily operating times per vehicle due to autonomy restrictions);
2. The technical solution should not imply constraints for the bus driver during the operations.

#### 3.1.3.2 Technical bids and final choice

In 2015, few manufacturers were able to answer the call for bids for 24-meter-long electric vehicles (see Table 3) and the associated charging system:

- Heuliez, Iveco, MAN, SCANIA, SOLARIS and Volvo did not offer such kind of low floor vehicle at the time.
- Mercedes-Benz-EvoBus only had the 21-meter-long "Citaro CapaCity L" diesel model. As mentioned, diesel-fuelled vehicles were disregarded.
- The Swiss manufacturer HESS developed and deployed double-articulated hybrid buses since 2009. The first vehicle has been on regular duty since 2009 in Luxembourg. In 2015, HESS tested fully electric mono-articulated buses in Geneva. More details are given in Section 3.2.1.
- The Belgian manufacturer VAN HOOL had already deployed different 24-meter-long buses in 2015. They only had a 19-mter-long fully electric bus demonstrator. These fully electric 18-meter-long buses were tested in 2016 in Hamburg, Germany. VAN HOOL deployed fully electric 24-meter-long buses in Linz, Austria, starting from 2017.

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**Table 3: Comparison of existing 24-meter-long bus systems in 2015 (Source: Nantes Métropole technical note)**

| | | Drive system | | | | |
|---|---|---|---|---|---|---|
| | | CNG | Diesel-electric hybrid | Electric | CNG-electric hybrid | Diesel |
| Manufacturer | Mercedes-Benz-EvoBus | No | No | No | No | 21-meter-long Citaro CapaCity L |
| | HESS | No | 24-meter-long lighTram® buses. Deployed in Luxembourg since 2009 and tested in other cities (Geneva, Lucerne, Zurich, Munich, Hamburg, Utrecht, etc.) | Demonstrator and in deployment in Geneva (18-meter-long buses) | No | No |
| | HEULIEZ | No | No | No | No | No |
| | IVECO | No | No | No | No | No |
| | MAN | No | No | No | No | No |
| | SCANIA | No | No | No | No | No |
| | SOLARIS | No | No | No | No | No |
| | VAN HOOL | No | 24-meter-long Exqui.City buses. Deployed in Metz (France) since 2013 and in deployment in Fort-de-France (Martinique) | Demonstrator only (18-meter-long buses) | 24-meter-long Exqui.City buses. Deployed in Malmö (Sweden) since 2014 and Bergen (Norway) since 2014 | NewAGG300 Deployed since a long time ago (Utrecht, The Netherlands; Hamburg, Germany; Luxembourg, etc.) |
| | VOLVO | No | No | Uncertain | No | Uncertain |

Nantes Métropole publicly launched its call for bid in July 2016 with a deadline in September 2016 for offers. They received two complete tenders: one from HESS and the other one by Van Hool. Two additional incomplete applications from Solaris and SILEO GmbH were ignored. As required, the tenders from HESS (together with ABB for the charging system) and Van Hool (together with Siemens or Mobility Way for the charging system) proposed a basic offer with different variants. Meetings between SEMITAN, mandated by Nantes Métropole, and each company allowed to get a deeper understanding of each solution and to detail each offer. These offers were then analysed and ranked according to the following criterions:

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- Technical value mainly based on the vehicle capacity, on the vehicle performances (notably in terms of gyration, acceleration and speed, passenger flow) and on the performances of the electrical system (daily autonomy as a mix of batteries capacity and the power of the charging stations as well as impacts on the operations). A particular attention has been also paid to the ergonomics for drivers;
- Total cost of buses and charging system;
- Estimated cost of use including maintenance cost and fuel cost;
- Environmental impacts that cover noise and also lifecycle analysis about the batteries.
- Ability to deliver the buses and the whole charging system with respect to the given schedule;
- After-sales service.

Both propositions obtained a note for each criterion and a global weighted mark. Based on the ranking, Nantes Métropole and SEMITAN finally decided to select the solution proposed by HESS together with ABB. The buses and the charging system are described in the next Section.

## 3.2 Presentation of the eBusway system

This section is devoted to the presentation of the eBusway system, including the buses and the charging system both on the bus and the fixed infrastructure.

### 3.2.1 Presentation of the buses

As already mentioned above, Nantes Métropole together with SEMITAN have chosen the offer made by HESS. In the remaining, the selected HESS buses are described.

#### 3.2.1.1 Quick description of the HESS lighTram® 25 buses

The Hess lighTram® 25 is a bi-articulated bus. The Swiss company Carrosserie HESS AG produces the chassis as well as the bodywork. The HESS buses benefit from the patented Co-Bolt® system for aluminum body frame that allows easy repairs and very good durability over time. ABB company provides the propulsion system as well as the charging system. The buses are assembled in Bellach, canton of Solothurn, Switzerland. The lighTram® 25 is 24.5-meter-long for 24.6 tons and has a full low floor. It has four axles, two in the front part and one in each articulated part. The second and third are motorized while the first and fourth are adjustable. See Figure 5.

In brief, here are the specificities of this bus:

- Dimensions: 24.5 m long, 2.55 m wide and 3.50 m high;
- Weight: 25.3 tons (empty weight) and 39 tons (gross weight);
- Capacity: 150 passengers with 40 seated and 108 standing (assuming a maximal density of 4 passengers/m$^2$); 2 places for disabled;
- Facilities: an access ramp for the disabled at door 2; six 38-inch information screens;
- Two in-wheel permanent magnet motors (second and third axles) with water-cooling;

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- Two directional axles (first and fourth axles);
- Max speed of 80 km/hr.

**Figure 5: Picture of the eBusway during its official presentation in front of the Nantes castle, on December 12, 2018 (Credit: Christiane Blanchard / SEMITAN)**

**Figure 6: Front view of the eBusway (Credit: Christiane Blanchard / SEMITAN)**

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#### 3.2.1.2 Other HESS bus models: examples in Europe

There exist two main HESS electric bus models: the lighTram® 19 and the lighTram® 25. The first one is a 18.7-meter-long mono-articulated bus. The second one is a 24.7-meter-long bi-articulated bus. The latter is the selected version by Nantes Métropole. Any of these models can be combined with one of the following different charging technology:

- Dynamic Charging (DC), say the bus is permanently linked to the electric current thanks to a catenary for instance;
- TOSA by ABB that is the chosen system in Nantes. This technology is detailed in Section 3.2.2;
- Opportunity Charging (OPP) by connecting the bus at terminal stations thanks to a pantograph positioned either on the rooftop of the bus or at the station.

For instance, the lighTram® 19 together with TOSA charging system by ABB, was tested from May 2013 to March 2014 and then deployed in December 2017 (it started public operations in March 2018) on bus line 23 of TPG network (Transports Publics Genevois) in Geneva, Swiss.

As presented in Section 3.2.2, the choice in Nantes was to promote the TOSA system with some charging stations along the line, in order to:

- Avoid the installation of overhead power lines necessary for Dynamic Charging;
- Limit the volume and weight of embarked batteries in the buses in comparison to charging buses at night;
- Prevent any impact of the charging times on the line operations. For instance, there is no needs for longer stop times at the stations or the connection and disconnection are also automatic and do not require any particular action form the bus drivers.

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**Table 4: List of HESS bus combination and some deployment examples**

| | lightTram® 19 bus model (mono-articulated, 18.7m) | lightTram® 25 bus model (bi-articulated, 24.7m) |
|---|---|---|
| **Dynamic Charging (Trolleybus; partial charging thanks to catenary)** | *Branded as SwissTrolley® 19 DC*<br>Biel, CH<br>Zürich, CH<br>Salzburg, AT | Lines 5 and 20, Bern, CH<br>Line 20, Lausanne, CH<br>Lines 1, 2 and 8, Luzern, CH |
| **TOSA (charging at some stations)** | Line 23 Tpg, Geneva, CH | **Busway line 4, Nantes, FR** |
| **Opportunity Charging (charging by pantograph at the terminus stations only)** | Line 17, Bern, CH | / |


**Figure 7: Pictures of TOSA buses in Geneva (Credit: Tpg & HESS websites)**

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lighTram® 19 OPP (opportunity charging)

lighTram® 25 DC (Dynamic Charging)

**Figure 8: Pictures of Bern buses (Credit: BERNMOBIL website)**

**Figure 9: Picture of lighTram® 25 DC in Luzern (Credit: Verkehrsbetriebe Luzern website)**

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#### 3.2.1.3 Exterior and interior designs

For the exterior design, for sake of homogeneity of the whole SEMITAN rolling stock, the eBusway buses will inherit the livery, which has been used on the TAN buses since 2016 (notably on the Iveco Urbanway 18 CNG buses running on Chronobus lines C1, C2, C6 and C7). This livery introduced by Nantes' company GRAPHIBUS allies a majority of white and green colours (see Figure 10) together with the black of the windows. Some curves run on the side to break the windows' horizontal alignment and to emphasize the idea of movement. A green comma underlining ups and downs is associated with these curves.

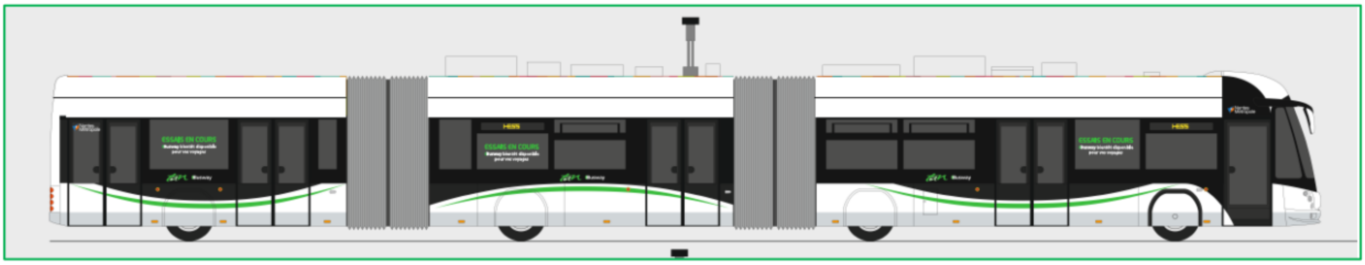

**Figure 10: Livery of the eBusway (Source: GRAPHIBUS / SEMITAN)**

In the same spirit of homogeneity, the interior design is similar to the previous TAN buses as well (see Figure 11). The purpose of the choice of colours and interior materials is based on a desire for harmony of colours, sobriety and clarity in order to highlight the space. The idea is to give a real perspective and maximum input of natural light to encourage travellers to better position themselves in the bus. AVANT-PREMIERE, a French design agency based in Lyon, imagined this interior.

**Figure 11: Inside view of the eBusway (Credit: Christiane Blanchard / SEMITAN)**

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The Italian company RUSPA supplies the seats. Their structure is the “citipro” model whose backrest is backlit. All the seats will be equipped with USB sockets, allowing charging of personal mobile equipment.

The seat fabric made by the company LANTAL (Swiss company), was created specifically for the TAN network based on its original trademarked colour. Two colours are used at random on the seats for a more modern outcome: for the most part a deep green, in order to convey a "zen" and calm spirit and an acidulous green to bring a dynamic note to the furniture. Folding seats as well as support and grab bars for standing passengers complete this feature.

The floor (produced by the French company GERFLOR) matches the current trends for this type of buses. It is an imitation parquet bringing warmth to the whole. The risers in solid colour are matched to the ground.

While the structures are in light grey so as not to darken the interior, the rest of the vehicle (ceiling, walls, uprights) remains in solid colours (without patterns) from ecru to deep beige chosen in order to attain sobriety and ease of maintenance. The joints between the different boxes of the vehicle are partly translucent to let the outside light enter as much as possible. The four double doors and the internal organization of the bus, allow a better fluidity of the passenger exchanges (in particular entrances / exits) and people distribution in the vehicle.

The main light and bright slabs on the ceiling complete the homogenization of the interior. A large bay window unfolds at the back of the bus. The ceiling is embellished with a screen-printed grey vegetable motif.

The six dynamic information panels identical to those of recent buses, were designed in collaboration with the company LUMIPLAN based in Saint-Herblain, in Nantes metropolitan area. With a diagonal of about 1 meter, it is the largest model on the market. The objective is to offer customers real-time information (progress of the line in the form of a thermometer, announcement of the next stop, correspondences, planned disturbances, traffic info, etc.) and commercial news, in a visual and sound way.

### 3.2.2 Presentation of the charging system

The charging system for buses and stationary cranes is the TOSA system of the Swiss-Swedish company ABB (Asea, Brown and Boveri), supplier for HESS of the complete traction chain including the batteries, the converter and the traction engines. TOSA originally stood for the four partners who initiated the project[2] and it was redesigned to match the acronym of the French “Trolleybus avec Optimisation du Système d’Alimentation” (Trolleybus with optimization of the energy supply system).

[2] The four partners were Transports publics genevois (Geneva public transport operator), Office de la promotion industrielle (the Swiss Office for the promotion of industries and technologies), Services industriels de Genève (Geneva power utility) and ABB group.

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#### 3.2.2.1 Bus charging equipment

The system chosen on the eBusway is called "bottle feeding". It charges the vehicle's batteries, which are located on the roof of the bus, during its stops. They are charged through stations which are connected to the general electricity network. At each equipped station, the vehicle is quickly recharged using a telescopic device mounted on the roof of the bus (see Figure 13). Thanks to the detection of a RFID (Radio Frequency Identification) beacon, the arm rises when the bus is approaching the fixed recharging bracket to ease the prepositioning at a distance up to 30m. Then, the arm is guided thanks to an optical laser sensor.
The batteries on the roof are charged on average every fourth stop, while the passengers get on and off. This charging process takes place only during the dwell time.

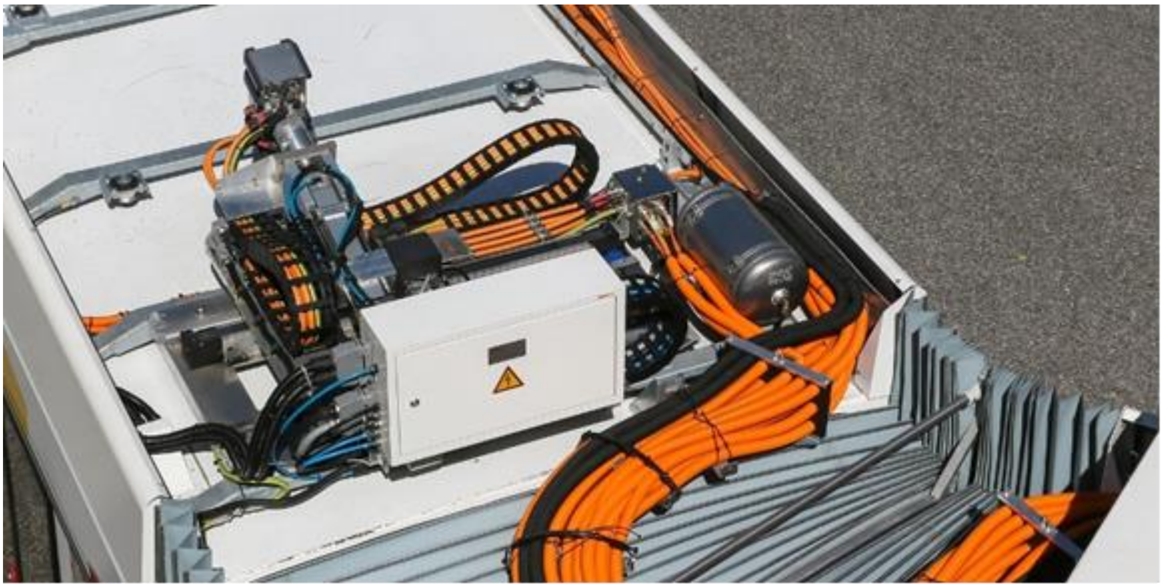

**Figure 12: Picture of the articulated arm on the bus roof – TOSA experiment in Geneva (Credit: ge.ch website)**

The TOSA bus batteries are located on the roof of the vehicle, which ensures a flat and low floor over the entire length of the bus. They will have an electrical storage capacity of about 128 kWh for a weight of just one ton. In comparison, the capacity of Tesla S cars varies, depending on the model, from 60 to 100 kWh. A Renault Zoé has a capacity of 40 kWh: hence, one eBusway has an equivalent capacity of three Renault Zoé for a passenger capacity multiplied by thirty. TOSA buses do not require high power batteries since autonomy is not a major factor. This is due to the "bottle feeding" technique, which allows the partial recharge of the bus's batteries during the journey. Therefore, the TOSA buses need to carry a lot less batteries than an electric bus that would be charged at night only. Indeed, batteries for a 300-kilometer autonomy would take up to 12 tons more. Knowing that 12 tons is the approximated weight of 150 passengers (with an average weight of 80kg per passenger), this means that with such batteries, the

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bus could not embark any passenger. Putting fewer batteries therefore saves 10% of potential electric consumption because the vehicle is lighter.

Hence, TOSA buses carry more passengers and fewer batteries than conventional electric buses, which is obviously also positive for the environment because it represents fewer batteries to recycle.

#### 3.2.2.2 Charging infrastructure

In addition to the energy transfer system installed on the roof of the buses, the TOSA technology also consists of charging stations located at certain stops along the route that allow the transfer of energy between the general electricity network and the batteries of the vehicles. .
ABB usually proposes three possible types of charging stations:

- Flash Feeding Station (FFS) that is the solution that has been deployed in Switzerland and has the following properties:
  - Only a few seconds to be connected and disconnected to the bracket at stations;
  - 20 to 30 seconds to charge at least partially the embarked batteries with a 600 kW power.
- Terminal Feeding Station (TFS) able to provide energy during temporary stops at stations while it would take approximately 5 minutes to charge the embarked batteries with a 400 kW power at terminal stations to reach a full autonomy on a round trip on the line.
- Depot Feeding Station (DFS) that is mainly used for a slow recharge during the night when the bus is stopped.

In Nantes, the selected solution is a mix between flash feeding stations and terminal feeding stations. Indeed, the principle of FFS is used to partially recharge the on-board batteries at some intermediary stations with a 600 kW power and for less than 30 seconds, i.e. the time it usually takes to pick up or set down passengers at bus stops.
Usually, FFS contain a storage module, which can limit peaks of electrical consumption. This module is usually made up of lithium ion batteries (LIB), chosen for their considerably smaller volume and lower cost. In Geneva, these batteries have been designed with a large storage capacity of 88 kWh. This is sufficient to supply full power whilst maintaining sufficient reserves to handle a bunch of many buses i.e. one bus following another. This charge/discharge cycle affords an estimated service life of 10 years for the LIB module of the flash feeding stations. In Nantes, such electric storage module has been disregarded.

The role of the terminal feeding stations is to fully charge the vehicles' batteries while they are stationed at the end of the line (four to five minutes) awaiting their next departure. Given the high utilisation rate (very brief intervals between each recharge), these stations are not equipped with an energy storage module (such as batteries, supercapacitors, etc.) that could reduce the connection power. The latter is 600 kVA, offering an output power of approximately 550 kW.

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Such stations have been deployed in Nantes, including at the intermediary stations on the line (Gréneraie and Beaulieu stations). In Nantes, this type of solution, namely TFS, has been preferred to FFS for three reasons:

- The French electrical network proposes a high voltage current (HVA) that is cheaper than low voltage (LV) one (which is not the case in Switzerland where low or medium voltage are cheaper than high one);
- TFS do not need to install batteries or supercapacitors for the electric storage; hence, it is less expensive to deploy on the field. In addition, maintenance costs are also lower since the battery packs have to be replaced after 10 years;
- TFS imply less electric losses than FFS since there are no needs for batteries and there are less electric transfers. The energy efficiency from the transformer to the bus batteries is 25% better for HVA than LV;
- TFS allow for a better resilience and ruggedness in case of events that might lead to a frequency increase. There is no need to dimension the substation battery pack with respect to the frequency and duration of charging operations.

A recharge bracket, called totem, which is over 4.5 metres tall and supports a 2 m long rail in order to connect to the vehicles' automatic articulated arm, supplements the infrastructure of the terminal feeding stations. This rail, located 4.5 metres above Street level, is used to transfer energy between the electric cabinets and the buses' batteries. When no arm is connected to the rail, there is no electrical current in the bracket or the rail, thereby ensuring total security. As energy is transferred by contact, it does not generate any electromagnetic fields, unlike other energy-transfer technologies such as induction.

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**Figure 13: Close-up pictures of the recharging prototype system (Credit: Christiane Blanchard)**

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**Figure 14: Picture of one eBusway with charging totem at terminal station Porte de Vertou (Credit: Guillaume Costeseque)**

## 3.3 Preparation and roll-out

This section is devoted to the presentation of:

- The necessary civil engineering works for the adaptation of the existing infrastructures;
- The testing period of the bus.

### 3.3.1 Civil engineering works

The majority of the stations on line 4 was designed for 24-meter-long vehicles, even at the starting of Busway project in 2005. However, to ease the arrival of longer full-electric buses, the SEMITAN needs to arrange some stations accordingly and to install the recharging systems for the bus batteries at some stations of line 4. The SEMITAN also needs to create a specific Technical and Operations Center, called CETEX, to host the buses outside of their operating periods and for maintenance purpose as well. Hereafter, we detail the works that have been pursued for the arrival of the eBusway.

These infrastructure costs were evaluated at 1.5 millions of Euros in 2015.

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#### 3.3.1.1 New technical and operations centre (CETEX)

**Figure 15: View of the future CETEX site (Source: SEMITAN)**

In order to accommodate, maintain and manage the operation of eBusways, a new technical and operating centre (CETEX) of 18,300 m² is under construction in the Nantes metropolitan area starting from January 2019. This site hosts the eBusways and incudes a service room, a workshop, two electric charging points, a washing machine and other maintenance equipment (lifting, braking bench, etc.). During its construction, a temporary site very close to the definitive CETEX has allowed the storage of the buses and the electrical supply of the vehicles thanks to a proto-charging totem while the maintenance was done at another technical centre operated by SEMITAN in Trentemoult. The roof of the definitive CETEX will be equipped with photovoltaic cells that can provide electricity for 1 to 2 buses.

#### 3.3.1.2 Adaptation of existing infrastructures

The civil engineering works are scheduled throughout 2019, while maintaining the operation of Line 4 as much as possible. These works have several objectives:

- To adapt the infrastructure (station, terminus, turning zone) to facilitate the circulation and parking of longer eBusways.
- To deploy the charging system at both intermediary stations (Beaulieu and Gréneraie) and at both terminals (Foch-Cathedral and Porte de Vertou) as well: the charging system includes totems, electrical substations and all the necessary electric connections.
- To renovate the platforms at Beaulieu and Gréneraie stations.
- To set security features such as pedestrian traffic lights near intersections crossed by the e-Busway.

Below are the details of the works at each concerned station:

- Terminus station Foch Cathédrale (from January to July 2019):
  - The works aimed at demolishing the former bus exchange hub with the goal of rebuilding it entirely in a definitive way. Another objective is to make it more easily accessible to people with reduced

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mobility. The exchange hub will be "realigned" to preserve the historic urban composition of the square and the reorganization of the urban space to ensure the gyration of longer buses in the square, taking into account the recommendations of the architect of the Bâtiments de France on this classified historic site. The quays are made of granite slabs, in the same tones as those of existing granite pavers on the site to preserve a coherence of material. A precise and subtle layout of the platforms and paths visually gives the impression that the access ramp is "lifted" from the pedestrian path to the wharf, without breaking. The island-dock for the implementation of self-service bikes is expanded.

    - The supply of electrical energy is guaranteed thanks to the establishment of charging totems, as well as the creation of an electric substation nearby. The energy substation was installed in March in the Parking Cathédrale. New furniture (identical to the current in terms of design) are installed in May. The two 600 kW recharge totems are erected in August. The finishes followed, including the connection of the cables between the substation and the charging totems of about 150 meters. The tests started in October.
- Terminus station Porte de Vertou (from January to August 2019):
    - This terminus is completely redesigned (see Figure 16) to ease the flowing of the different users: pedestrians, bicycles, cars and eBusway vehicles. A new parking-silo relay currently under construction completes the transformation of this pole.
    - Four positions with their own recharge totems were created for the 24-meter-long buses to facilitate especially the parking of buses during the times of regulation.
    - A semi-underground electrical substation was installed near the future parking-relay in silo.
- Ile de Nantes station (from April to June 2019): the works aimed at adapting the platform to the new size of the vehicles, by extending them by 11 meters. Hence, this station can eventually accommodate at the same time the 24-meter-long eBusways from Line 4 and the 18-meter-long buses from Chronobus Line 5. With this new configuration, crossings in this area are rehabilitated to facilitate the movement of pedestrians. Like the station Gréneraie (see below), areas of extraction and insertion for the buses (from and to the dedicated lines) are created at Ile de Nantes station.
- Gréneraie and Beaulieu stations (from April to June 2019)
    - The objectives were (1) to renovate the station platform, (2) to create extraction and insertion zones for the buses and (3) to create electric substations and the installation of electric charging brackets (or totems).
    - Gréneraie and Beaulieu stations platforms needed to be renovated, since normal degradations have emerged, including rutting at the stations. This is due to several factors:
        1. The busway stops almost always at the same place;
        2. The mix of stations is aging;
        3. The heat emitted by the exhaust gases from the buses speeds up this process.

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- Since 2016, the refurbishment of busway station platforms has been carried out in reinforced concrete for better durability of the structures (crack limitation). The stations Gréneraie and Beaulieu are redone with this same technique.
- In the event of disturbances (vehicle breakdown, interventions, work in a station, etc.), extraction and insertion zones will be created upstream of the station, which will facilitate the operation of e-Busways, in particular turnarounds, so more readable for other users of public space, and safer. Pedestrian crossings around these areas are secured by the installation of traffic lights.
- Beaulieu sub-station of about 55 m$^2$ is integrated into a vegetated slope for a better urban integration. Several technical elements are implemented on this site (including an ENEDIS transformer).
- Gréneraie sub-station of approximately 55 m$^2$ is inserted in a former operating site, which was enlarged accordingly. Two electric charging totems per station were installed. Due to the particular configuration of the Gréneraie station, which is very close to road traffic, the construction site area has needed specific security caution.

(a) Picture of 2018 situation

(b) Synthetic view of future situation

**Figure 16: Planned transformation of Porte de Vertou station (Credit: SEMITAN website)**

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- Chapeau Verni station (from July to September 2019)
  - In order to facilitate Line 4 operations and to improve its travel time, the works aimed at eliminating the single route that integrates the passenger station. Formerly, the buses in both directions (single lane) took the station in the direction of the city center. This requires that the busway in the direction of Vertou wait for the end of passenger exchanges of the bus in the opposite direction, to be able to access its own station.
  - Hence, the station in direction of Nantes city center is moved at the side of Parking-Relay in the general circulation.
- Duchesse Anne station (July-August 2019)
  - These works aimed at reorienting the platforms, renovating the coating of the station and facilitating the operation of the e-Busway. The platforms were demolished and rebuilt with a new orientation. In addition, thanks to the creation of a new roundabout during the summer near the station, a new turning point is created to bring the passenger closer to the terminal point, in case of disturbed situation and to guarantee a correspondence with Tramway Line 1. The coating was completely redone in reinforced concrete.
  - The traffic plan has been reviewed along the eBusway path (Henri IV Street, Oratoire place) to ensure the priority and regularity of public transport, but also to incorporate the necessary changes following the development of the Nantes promenade between Gare Nord-Jardin des Plantes. and Duchesse-Anne.

### 3.3.2 Testing planning of the HESS buses

A testing phase of the new eBusway has been necessary to get used to this new vehicle, to teach drivers how to manipulate it, to see the potential drawbacks or failures of the system and try to find solutions.

In December 2018, Nantes Métropole and SEMITAN received the first eBusway from HESS. In January 2019, they started testing the vehicle capacities: this included gyration tests along the path as well as tests of the electric autonomy on a journey. During this first step, the vehicle did not embark passengers. Operations on Line 4 were still done with the Mercedes Citaro buses. In August 2019, SEMITAN received the homologation of the HESS vehicle. Following this agreement, they started a testing period with on board passengers. Operations started in September with an incremental number of HESS eBusway substituting former Mercedes buses. By the end of 2019, all the twenty-two eBusway buses will operate on the line.

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# 4. Charging infrastructures for private electric vehicles and electric bicycles

## 4.1 Description of the action

As part of the mySMARTlife project, Nantes Métropole is committed to the deployment, by 2020, of 65 smart and connected charging points for electric vehicles (EV) in the car parks located in the metropolitan area center.
More specifically, Nantes Métropole commitment provides for the installation of "supervisable" charging points, divided into:

- 49 "slow" charging points
- 14 "accelerated" charging points
- 2 "fast" charging points.

Nantes Métropole's commitment also covers deployment of 500 secure charging points for electric-assisted bicycles (e-bikes).

One of the components of the project is also to connect the vehicle charging points with the urban data platform, so that data related to use and functioning of the equipment can be tracked in the Nantes Métropole information system. In a medium-term perspective, Nantes Métropole also aims at developing a new digital service in the "Nantes in my pocket" application, allowing users to be informed in real time about charging point availability.

## 4.2 Nantes Métropole strategy for promoting e-mobility (e-cars and e-bikes)

### 4.2.1 The Urban Mobility Plan as general framework of the metropolitan strategy

Since the law relating to the National commitment for the Environnement ("Loi portant engagement national pour l'environnement",, known as the "Grenelle 2" law in France) has been adopted on July 12, 2010, the Urban Mobility Plans (Plans de Déplacements Urbains) drafted by local authorities must deal with charging infrastructures for e-cars, in order to promote development of electric mobility. The legal framework for the deployment of charging stations has also been strengthened with the French law on the Energy Transition for the Green Growth (August 17, 2015).

In addition, in the Nantes Métropole area, transports account for about 42% of the local greenhouse gas (GHG) emissions and represent the main emission sector. Evolution towards less carbon mobility is therefore an essential condition for achieving the objectives set by the metropolitan council in terms of fight against climate change (Nantes Métropole objective consists on the reduction of annual emission per capita of 30% by 2020 and 50% by 2030 –

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compared to 2003). In this way, development of electric mobility is one of the means that local authorities can encourage to promote energy transition on their territory and to reduce GHG emissions of the transport sector.

Thus, the new Urban Mobility Plan approved by the metropolitan council on December 2018 mentions in its actions plan the wish of Nantes Métropole to promote the evolution of the cars stock of individuals and companies towards electric motorizations.

The Urban Mobility Plan also specifies the ambitions of the Métropole in terms of development of bicycle use: while bikes trip account for less than 4% of the total trips, the objective is to reach 12% by 2030. To this end, Nantes Métropole plans to develop dedicated infrastructures (implementation of structuring bike routes, extension of the cycling network, increase of bike parking supply…). Nantes Métropole is also focusing on the development of electric-assisted bicycles to reach a wider audience of users. In this regard, the new Urban Mobility Plan provides different kinds of measures, such as new offers for medium and long term rental of bicycles (including e-bikes), and deployment of secure charging points for e-bikes.

### 4.2.2 Strategy for the deployment of charging infrastructures in the Nantes Métropole area

- **Charging infrastructures for electric cars of individuals**

The wish of Nantes Métropole through its new Urban Mobility Plan is to reduce the space dedicated to cars in the city (both in terms of road and parking infrastructures), to the benefit of cycling, walking and public transport. Nantes Métropole promotes thus the principle of "quiet city" that must contribute to a better sharing of the public space between all modes of transport.
In the mobility field, the Nantes Métropole policy is to reduce motorization rate and to encourage individuals to renounce their second car by offering alternative transport solutions (public transport, cycling, walking).

In addition, the city center area is under heavy pressure on on-street parking. Indeed, despite regulations that strongly constrain occupancy periods of parking spaces and that seek to promote a better rotation (pricing system that encourages short-term occupancy), parking remains difficult. This generates significant durations for space parking researches for car drivers. This also contributes to road congestion and associated nuisances (air pollution, noise) in the city center.

For all these reasons, Nantes Métropole considered more appropriate to favor installation of electric charging stations in private spaces, where cars are parked on longer periods.

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However, in order to meet the growing needs of users in terms of electric-mobility, Nantes Métropole has committed to deploy a network of supervisable charging stations for e-vehicles, consistent with its parking policy[3].

Nantes Métropole has therefore chosen to focus on the deployment of charging stations in car parking facilities. These car parks, located in specific buildings are, generally used for relatively long periods, compatibles with charging times of e-vehicles. These long parking periods also make it possible to avoid installation of high power stations, and thus limit problems with the available power of the electric grid of car parks: in this way, charging stations can be connected to the existing grids, without additional electricity supply. The 15 car parks located in the center of the Nantes agglomeration are therefore the main vector of deployment of charging infrastructures for e-vehicles. Nantes Métropole owns these car parks, but different operators manage them: it is up to them to install and manage charging stations based on prescriptions defined by Nantes Métropole.

Concerning pricing, Nantes Métropole has chosen to let the charging operations free-of-charge (users only have to pay the cost for parking) for now. Nevertheless, in the future, it is possible that users could have to pay for charging operations. For that reason, charging stations are compatible with installation of devices for electronic transactions.

**Insert about the new Nantes Métropole policy regarding delegation of operation of car parks**

Until recently, Nantes Métropole entrusted operation of car parks to different operators based on various forms of contracting (delegation of public service, concession, services contract…).

In order to make the process simpler, Nantes Métropole engaged in 2019 an evolution of the operation methods of its car parks: now, the 15 cars parks are grouped in 3 perimeters (West Center, City Center, Railway station). Each group is subject to a public service delegation contract signed with an operator designated after a call for tender procedure. To date, two public service delegations contacts have been awarded:

- The six car parks of the “City Center” perimeter have been allocated to the public company “Nantes Métropole Gestion Services” (that is a local public company, whose capital is held in equal shares between Nantes Métropole and the municipality of Nantes).
- The five car parks of the “West Center” perimeter have been allocated to Effia company.

The contact for the operation of the 4 car parks of the “Railway station” perimeter should be allocated by the end of 2019. However, these car parks are for the moment already operated by Effia, which proceeded to the installation of some charging stations as part of its current operating contract.

3 Some car parks already had charging stations, but these charging stations were not numerous and not supervisable.

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- **Charging infrastructures for e-bikes**

Concerning the deployment of a network of charging points for e-bikes, Nantes Métropole's choices are part of the broader context of the metropolitan cycling strategy. This strategy has been updated in 2018 and resulted in the designation of a single bike operator (JCDecaux), responsible for deploying and operating all bicycles services on

**Figure 17: Car parks (on street or in facilities) with their previous / current and future operation modes (reference: Nantes Métropole)**

- **Charging infrastructures for e-bikes**

Concerning the deployment of a network of charging points for e-bikes, Nantes Métropole's choices are part of the broader context of the metropolitan cycling strategy. This strategy has been updated in 2018 and resulted in the designation of a single bike operator (JCDecaux), responsible for deploying and operating all bicycles services on the metropolitan area that were previously managed by different operators. This new global offer includes:

- **a short-term self-service bike rental offer** ("biclooplus" offer), with 1 230 bikes and 123 stations mainly located in the center of the Nantes agglomeration (around 21,000 subscribers).

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- **a long-term rental offer** (from one month to one year) for conventional bikes, e-bikes, folding bikes, or even cargo-bikes ("monbicloo / mybicloo"" offer).
- **a bike parking offer** with 2,400 secure sites ("bicloopark" offer). It is on these secure sites that Nantes Métropole chose to deploy the charging points for e-bikes.


**Figure 18: The different offers managed by the new single bike operator in Nantes**

Regarding charging points for e-bikes, sockets are installed in three types of locations:
- in spaces dedicated to bike park in car parks
- in parking lots specifically dedicated to bicycles ("véloparcs"), often located near park-and-ride sites
- inside secure individual boxes, implanted on the public space.

**Figure 19: Illustrations of secure parking solutions for bicycles in Nantes (spaces dedicated to bikes in car parks, specific bike-parks and individual boxes on public space)**

Recharging sockets thus constitute an additional service to the bike-parking offer. JCDecaux, as single bike operator is in charge of the promotion and commercialization of all the bike services. Nevertheless, regarding sockets in car

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parking lots, their installation is part of the public delegation contract concluded with the designated operators (Effia and NMGS) so that the operators have to support any necessary work.

**Table 5: Distribution of roles between single bike operator and operators of car parks**

| Signe bike operator (JC Decaux) | Car parks operators (Effia or NMGS) |
|---|---|
| - installs and manages access control equipment to space dedicated to bikes<br>- ensures the commercialization of the bike-offer<br>- creates and realizes the communication and signage supports<br>- manages customers relations, deals with complaints<br>- transmits to the car park operator the number of subscriptions, aggregates statistics for Nantes Métropole<br>- remove abandoned bikes<br>- inform car park operators and Nantes Métropole about malfunctions or interruptions of service | - carry out works for extension of premises dedicated to bicycle in car parks<br>- maintain the premises dedicated to bikes<br>- place signage about bike parking solutions in car parks<br>- transmit complaint to the single bike operator<br>- ensure security of the premises dedicated to bike park<br>- identify abandoned bikes<br>- inform Nantes Métropole about malfunctions or interruptions of service |

Finally, as for e-cars recharges, Nantes Métropole has chosen a free battery charging service, so that users have only to pay for the cost of the bike parking.

## 4.3 Charging stations for e-cars

### 4.3.1 Regulations and applicable standards in France for

- **Regulatory aspects**

In France, charging infrastructures for e-vehicles are governed by decree n° 2017-26 of 12 January 2017. This decree transposes different measures of the European Directive 2014/94/UE of the European Parliament and of the European Council of 22 October 2014 about deployment of alternative fuels infrastructures.

In terms of power, there are 3 technical levels for recharging:

– **« normal recharging »** (3.7 or 7 kVA, 16 amps single-phased), considered as the normal charging power. This level corresponds to the power of domestic sockets.
– **« accelerated normal recharging »** (or semi-fast) (22 kVA, 32 amps three-phased)
– **« fast » or « high-power recharging »**, allowing a transfer of electricity at a power level higher than 22 kVA (43 kVA in three-phased alternating current, 50 KVA in direct current). The Tesla superchargers for ultra-fast recharging enter also in this category with much higher powers (about 120 kvA).

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Increasing the recharging power makes it possible to reduce its duration, but not in a proportional way since the duration of recharging depends on the state of charge of the vehicle's battery.

**Theoretical duration of complete recharging of an electric vehicle with a 25 kWh capacity**

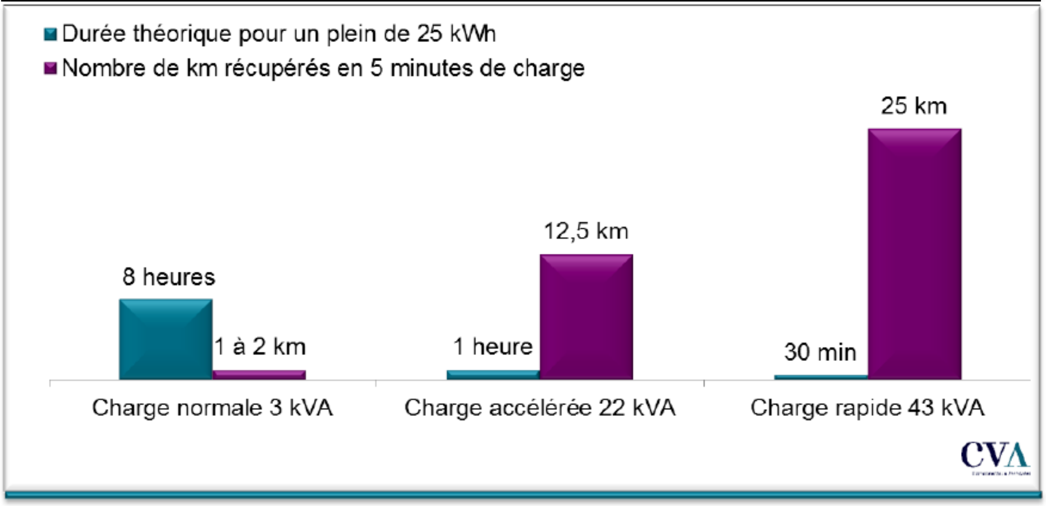


**Figure 20: Comparison of recharge times according to the power of the charging point used (reference: L. Nègre, 2011, *Livre vert sur les infrastrctures de recharge ouvertes au public pour les véhicules décarbonnés*)**

**In terms of security**, installation of charging stations in public car parks open to the public is subject to specific measures in relation with fire security. An official document, validated by the Central Safety Commission in 2012 (French organization that was previously responsible for defining protection measures in public-access buildings) specifies the applicable rules. These measures set a limit to fast charging stations installation, that are only allowed:

- in uncovered premises
- in roof terraces and at the firefighter-reference floor of ventilated car parks
- at the firefighter-reference floor, the floor below and the floor above, for covered car parks equipped with water sprinkler systems (if the security commission agrees).

- **Technical standards for the connection during charging**

The NF EN 61851-1 standard defines different types of connections, called « modes of recharging ».

- Mode 1: connection of the electric vehicle to the grid using conventional AC sockets (standard NF C61-314). There is no charging control and because of no dedicated circuit, power delivered is limited. This mode of connection is generally used for small e-vehicles or e-motorized two-wheeled vehicles. This type of connection may present a risk of overheating in case of too high amperage.

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- Mode 2: it has similar characteristics, with integration of a charging control device on the power cable supplied with the vehicle.
- Mode 3: it presents a control device that is directly integrated in the charging point, and has a dedicated electric circuit. That allows communication between the station and the vehicle, so that the station can regulate the charging power. This mode operates in alternating current with specific sockets (type 2 or type 2S, NF EN 62196-2 standard – see below). Powers can be up to 43 kW.
- Mode 4: it has similar characteristics to mode 3, but in direct current and with specific sockets (type Combo2 or CHAdeMO - NF EN 62196-3 standard), for higher delivered powers.

- **Standards for sockets (connectors)**

Different types of sockets are marketed or under development in France and in Europe. Some of them are reserved for certain powers and charging modes.

- **Type E**: domestic socket, compatible with charging modes 1 and 2
- **Type 2:** socket developed for the mode 3, in accordance to the European standard
- **Type 2S**: this socket is based on the type 2 and is its secured version (with a shutter plate). This type of connector has been developed to meet the French regulations that impose "shutter plate" for all car-charging sockets installed in domestic environments or in premises accessible to employees.
- **Type 3**: type of socket mainly developed in France. It will be replaced by type 2S and will disappear.
- **AA CHAdeMO** configuration: connector used for direct current fast-charging (standard used in many countries and developed by many manufacturers).
- **Configuration FF Combo2S:** connector reserved for fast-charging in direct current. It is the standard chosen as European standard.

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| Type de socle de prise ou connecteur | Illustration | Description | Compatible puissances élevées | Conformité à la réglementation française côté infrastructure |
| --- | --- | --- | --- | --- |
| Type E |  | Socle de prise type « domestique » compatible avec le Mode 1 ou 2 | Non | Oui |
| 62196-2 Type 1 |  | Connecteur dédié côté véhicule, non envisagé côté infrastructure | Oui | n/a (uniquement véhicule) |
| 62196-2 Type 2 |  | Socle de prise élaboré pour le Mode 3, conforme au standard européen | Oui | - oui sur la voie publique (ou assimilable); - non dans les locaux domestiques et assimilés, du fait de l'absence d'obturateurs |
| 62196-2 Type2S |  | Socle de prise élaboré pour le Mode 3, conforme aux réglementations européenne et française | Oui | Oui |
| 62196-2 Type 3 |  | Sera progressivement remplacé par un type 2S dans les bâtiments résidentiels (individuels ou collectifs), où la présence d'obturateurs est exigée. | Oui | Oui |
| 62196-3 Configuration AA CHAdeMO |  | Connecteur réservé à la charge rapide en courant continu (dédié côté véhicule, non envisagée côté infrastructure) | Oui | Oui |
| 62196-3 Configuration FF Combo2 (CCS) |  | Connecteur réservé à la charge rapide en courant continu (dédié côté véhicule, non envisagée côté infrastructure | Oui | Oui |

**Figure 21: Main types of connectors marketed or under development in Europe (reference: Guide technique pour la conception et l'aménagement des IRVE, 2014)**

In order to allow all users to use public-access charging stations, whatever their vehicle (and therefore the mode of charge and the type of connector), the French technical guide for design and development of recharging infrastructures for e-vehicles[4] defines recommendations regarding equipment of charging points.

For the "normal recharging" (3.7 or 7 kVA) and the "accelerated charging" (22 kVA), the technical guide recommends installation of 2 sockets for each charging point:

- a E-type socket for mode 1 or mode 2 recharging, in order to meet need of old generation vehicles, some hybrid vehicles or even e-bikes.

[4] French Ministry of Economy and Finance, 2014, *Guide technique pour la conception et l'aménagement des infrastructures de recharge pour véhicules électriques et hybrides rechargeables*, 36 p. https://www.economie.gouv.fr/files/files/PDF/guide_irve.pdf

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- a type 2 (or 2S) socket to ensure mode 3 recharging.

For fast recharging (43 kVA), the technical guide recommends installation of 3 cables per charging point to offer solutions compatibles with the different technical choices developed by cars manufacturers:

- one cable with a type 2 connector
- one cable with a CHAdeMO connector
- one cable with a Combo2 connector.

### 4.3.2 Description of the implemented charging stations and of their functionalities

- **Number and localization of the charging points**

Nantes Métropole initial commitment was to deploy 65 smart charging points for e-vehicles in 2019 and 30 in 2020. However, the total number of points will be higher and their deployment will be achieved faster than expected. Indeed, 111 charging points have been or will be installed by 2019 in the car parks of the 3 perimeters “Railway station”, “West Center” and “City Center”. Of these 111 charging points:

- 12 have been installed in 2018
- 26 have been installed in 2019 replacing former non communicant charging points
- 73 new charging points have been or will be installed soon during this year to complete the offer at the metropolitan level.

The deployment will continue in 2020, with installation of 27 additional charging points, then in 2021 with 24 other new points, bringing the total number to 162. IN a further horizon, the network of charging points installed in car parks is expected to reach 189 points.

In addition, there are also some charging points located in private car parks, or even on supermarket parkings. For instance, Effia plans to install a dozen of charging points in one of its own private car park, near the railway station (car park “Gare Sud 1”). .

A complementary offer will also be available when new Park-and-Ride parks located in Porte de Vertou and Neustrie will be commissioned.
The details of the deployment of charging points per year and per car parks are specified in the table below.

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**Table 6: Number of charging points for e-vehicles in the parkings of the 3 perimeters "City Center", "West Center", "Railway station" (reference: Nantes Métropole)**

| Parking | Perimeter | Operator | Total number of parking places | Charging points for e-vehicles (in red: smart charging points) | | | | % of equiped places |
|---|---|---|---|---|---|---|---|---|
| | | | | 2018 | 2019 | 2020 | 2021 | |
| DECRE-BOUFFAY | City Center | NMGS | 538 | 0 | *6* | *6* | *10* | 2% |
| GRASLIN | | | 510 | 2 | *6* | *6* | *10* | 2% |
| TALENSAC | | | 351 | 2 | *6* | *6* | *10* | 3% |
| TOUR BRETAGNE | | | 671 | 0 | *6* | *6* | *10* | 1% |
| COMMERCE | | | 524 | 2 | *6* | *6* | *10* | 2% |
| FEYDEAU | | | 523 | 3 | *6* | *6* | *10* | 2% |
| **Total** | | | **3117** | **9** | **36** | **36** | **60** | **2%** |
| CITE DES CONGRES | West Center | EFFIA | 439 | 2 | *9* | *9* | *9* | 2% |
| MEDIATHEQUE | | | 418 | 2 | *17* | *17* | *17* | 4% |
| ARISTIDE BRIAND | | | 307 | 0 | 0 | *17* | *17* | 6% |
| LES MACHINES | | | 640 | 3 | *17* | *17* | *17* | 3% |
| DESCARTES | | | 244 | 0 | 0 | *10* | *10* | 4% |
| **Total** | | | **2048** | **7** | **43** | **70** | **70** | **3%** |
| GARE CHÂTEAU | Railway station | EFFIA (until 2019) | 597 | *6* | 6 | *11* | *11* | 2% |
| GARE SUD 4 | | | 435 | *6* | 6 | *13* | *13* | 4% |
| GARE SUD 3 (Ilot Jallais) | | | 592 | 10 | *10* | *10* | *21* | 4% |
| GARE SUD 2 (5B) | | | 490 | 0 | *10* | *10* | *10* | 2% |
| **Total** | | | **2114** | **22** | ***32*** | ***44*** | ***55*** | **3%** |
| **TOTAL** | | | **7279** | **38** | **111** | **150** | **185** | **3%** |

As mentioned above, the parking periods in these car parks are rather long. That reduces the need for high-power stations. The table below indicates the number of charging points according to their power level. It shows that 7 KVA charging points are between 2 and 4 times more numerous than 22 kVA charging points (allowing accelerated recharging).

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**Table 7: Power of charging points in Nantes Métropole car parks located in the 2 perimeters "City center", "West Center", Railway station" (reference: Nantes Métropole)**

| Parkings | Perimeter | Smart charging points for e-vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2018 | | 2019 | | 2020 | | 2021 | |
| | | 7kVA | 22kVA | 7kVA | 22kVA | 7kVA | 22kVA | 7kVA | 22kVA |
| DECRE-BOUFFAY | City Center | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| GRASLIN | | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| TALENSAC | | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| TOUR BRETAGNE | | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| COMMERCE | | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| FEYDEAU | | 0 | 0 | **4** | **2** | **4** | **2** | **8** | **2** |
| CITE DES CONGRES | West Center | 0 | 0 | **8** | **1** | **8** | **1** | **8** | **1** |
| MEDIATHEQUE | | 0 | 0 | **16** | **1** | **16** | **1** | **16** | **1** |
| ARISTIDE BRIAND | | 0 | 0 | 0 | 0 | **16** | **1** | **16** | **1** |
| LES MACHINES | | 0 | 0 | **16** | **1** | **16** | **1** | **16** | **1** |
| DESCARTES | | 0 | 0 | 0 | 0 | 0 | **10** | 0 | **10** |
| GARE CHÂTEAU | Railway station | 5 | 1 | 5 | 1 | 5 | 6 | 5 | 6 |
| GARE SUD 4 | | 5 | 1 | 5 | 1 | 7 | 6 | 7 | 6 |
| GARE SUD 3 (Ilot Jallais) | | 10 | 0 | 10 | 0 | 10 | 10 | 15 | 6 |
| GARE SUD 2 (5B) | | 0 | 0 | 0 | 10 | 0 | 10 | 0 | 10 |

- **Technical characteristics and functionalities of charging points**

At this time, the deployment process of charging stations is more advanced for car parks operated by Effia than for those operated by Nantes Métropole Gestion Services (NMGS). Thus, the precise characteristics of installed equipment (or that will be installed soon) can only be described for the Effia stations. For NMGS stations, concrete technical choices are not defined yet (at the time of writing of this deliverable, supply contracts have not been published). However, functionalities of stations will be quite similar because they will have to meet the same technical requirements defined by Nantes Métropole.

Effia has chosen to equip most of its car parks with charging stations provided by the company E-Totem that will also be responsible for the supervision[5].

5 Charging stations located in the car parks « Descartes » ans « Gare Sud 2 » will be provided by another manufacturer.

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The smart stations that have been chosen are composed with a box with 2 charging points, so that they can serve 2 parking spaces. As recommended, each charging point offers 2 types of sockets:

- a type E/F socket (domestic socket) for mode 2 recharging, according to the IEC 61851 standard for normal recharging (3 kvA)
- a type 2S socket for mode 3 recharging (with protection system) allowing recharging until 7 kvA or 22 kvA depending on the cases.

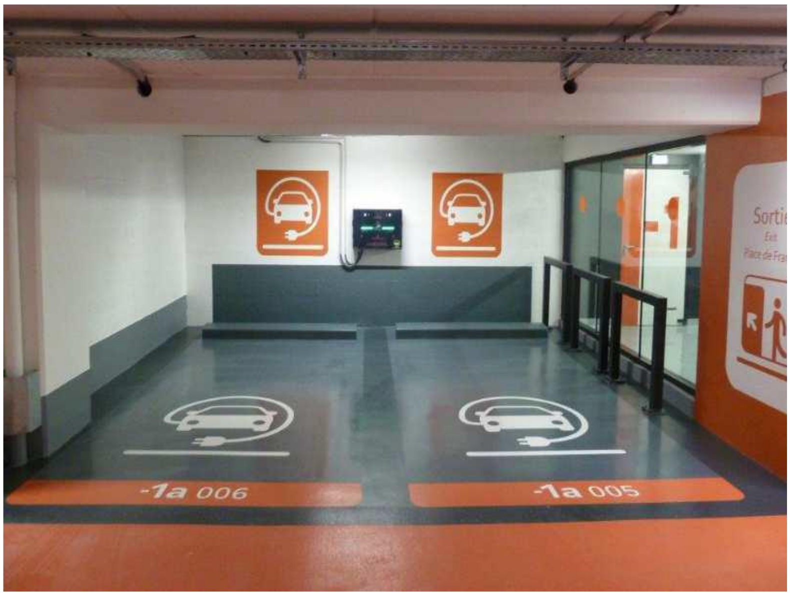


**Figure 22: Smart charging stations for e-vehicles in Effia car parks**

Each type 2S socket is locked and vandal resistant. Information for users are displayed on the front face. A light indication gives the status of the charging station (blue = available, green = unavailable, or red = charging). To access the charging points, users have to unlock it with personal RFID cards. Stations are also compatible with NFC technologies that could be offer to users in the future (to pay with smartphones for instance).

Charging stations are installed closest to the entry of parking lots. They are mentioned with specific materialization and adapted signage.

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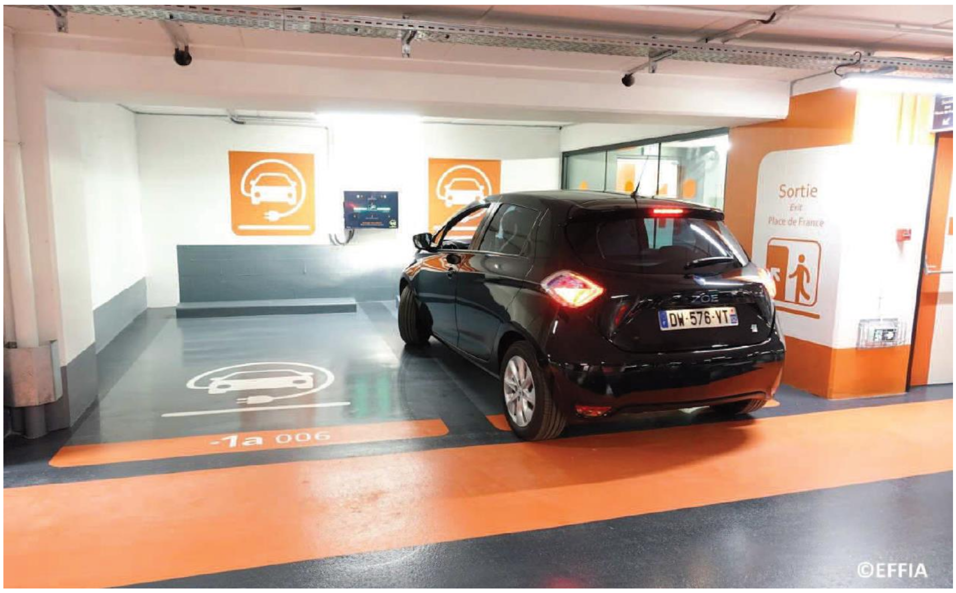


**Figure 23: Configuration of parking places with smart charging stations for e-vehicles in Effia car parks**

### 4.3.3 Effia supervision

Charging stations installed in Effia car parks are all connected to an information system with Internet access. A supervision software, reachable from classical web browser, provides access to two interfaces: one for “administrator profiles”, and one for “users profiles”.

**The administrator interface** allows operator to manage users (registration of new users to deliver them personal RFID cards for exemple), and to supervise and manage its charging stations pools on a remotely way. The software enables operator to obtain information and data about functioning of stations, statistics on electricity delivered, occupation rate per charging point… and information on customers. It is also possible to visualize the stations status (free, occupied, and damaged), to unlock stations or to restart it. Stations provided by E-Totem are also able to detect origin of faults, thus triggering targeted maintenance operations.

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Moreover, operators can manage the energy delivered by charging stations both on static or dynamic ways.
Static management makes it possible to define a power set point not to be exceeded on each site (car park) or on each charging station.

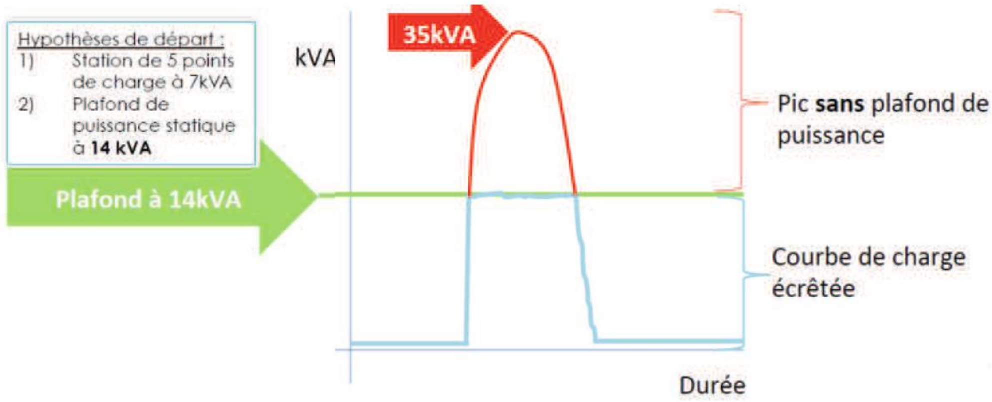


**Figure 24: Principles of energy management for charging stations (reference: E-totem)**

Dynamic management also allows definition of a maximum energy setpoint, but allows as well modulation of the energy delivered according to criteria such as time, user profile, or total energy consumption in the site and between stations. Power delivered by charging points can then be reduced to 3 kVA according to other electricity needs around.

**The users interface** allows users to order RFID individual access cards. It also allows users to access their customer-account. User interface also allows payment operations when this functionalities is installed (not yet the case for charging stations installed in Nantes car parks).

The management protocols are made under an open standard called Open Charge Point Protocol (OCPP 1.6); this protocol is scalable to the new versions (OCPP 2.0 for example). This protocol is widely used among actors of recharging infrastructures and allows charging stations remote management and supervision.

### 4.3.4 Urban data platform

In addition to the direct communication between the charging points and the supervision software, a communication protocol has also been established to ensure the feedback of information and its collection in the Urban Data Platform of Nantes Métropole.

To do this, the Open Interface Point Interface (OCPI) was chosen (it is viewed as an extension of the OCPP protocol used for the management of the charging stations).

The OCPI protocol was designed to support the communication between charging operators ("Charge Point operators") and "mobility operators" ("e-Mobility operators"), and ensure data semantic interoperability. It ensures

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inter-operability with recharging services in France and in Europe proposed by actors grouped in the GIREVE organization (GIREVE: “Groupement pour l'Itinérance des Recharge Electriques de Véhicules” or “Association for roaming of e-vehicles recharging”)[6]. This also makes it possible to provide billing services over charging operations.

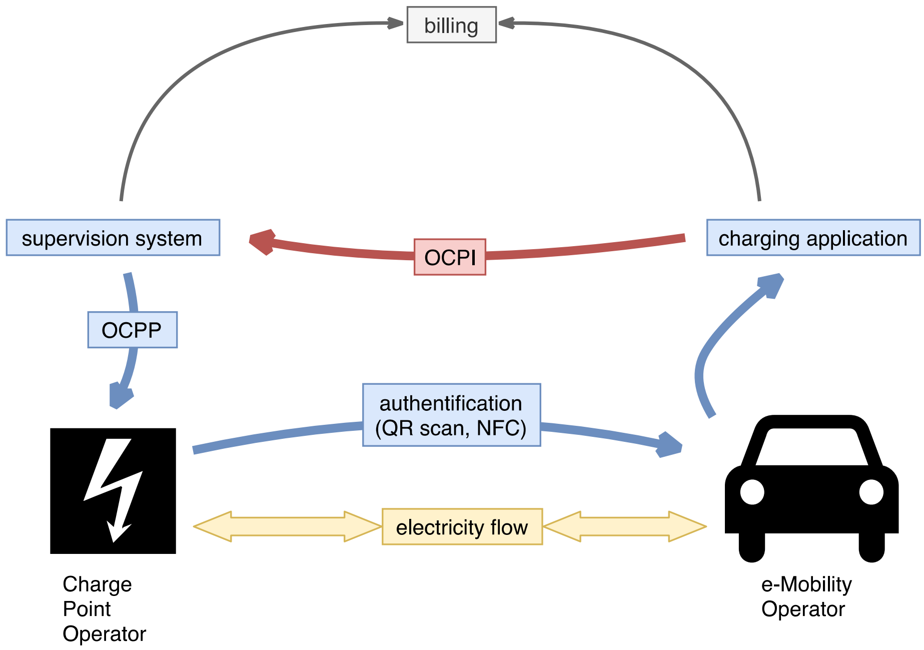


**Figure 25: OCPI in the EV charging ecosystem**

Effia, through its charging stations management partner e-Totem, has developed an OCPI interface to ensure connection with the data platform in order and to transfer information about the stations management system.

This needed specific digital development. In addition, within the OCPI organizational context, it was necessary to consider Nantes Métropole as a virtual mobility operator to give to the municipality read-access to the recharging operations of all Effia public stations located in Nantes territory.

On the Urban Data Platform side, Engie and Nantes Métropole have developed a specific OCPI connector, and carried out the necessary processing to enable the integration of data from the Effia API, the calculation of key performance indicators (KPIs), and the monitoring of the action.

[6] See: https://www.gireve.com/en

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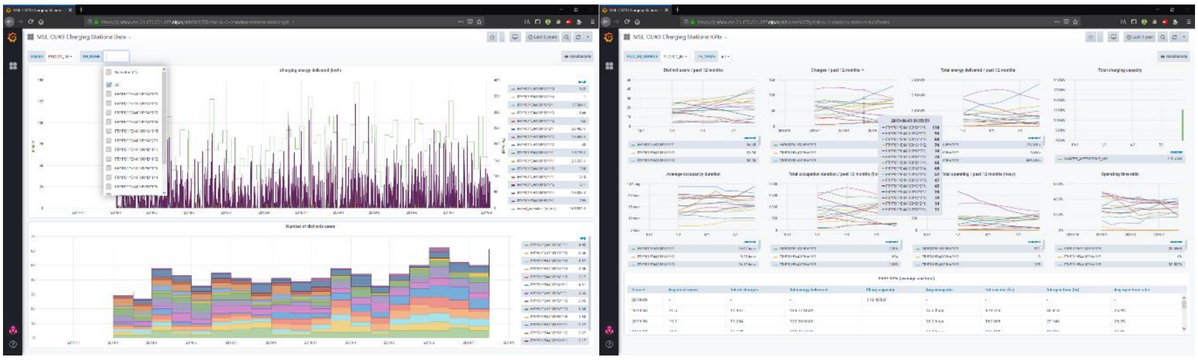

**Figure 26: Urban Platform EV charging stations monitoring**

From a prospective point of view, the idea of developing a specific visualization interface of the availability of charging stations in real time in the existing application "Nantes in my pocket" was studied. However, it should be noted that the Urban Data Platform is not necessarily the most relevant tool to offer this type of service in "real-time".

### 4.3.5 GDPR concerns

As per GDPR concern, a special attention was given to the observation data necessary to calculate the amount of users of each charging station. All charging session observation provide a unique identifier associated to the user who recharged its vehicle. Although this identifier is anonymized, the fact that one could determine the habits of a user in terms of when and where he or she would use the stations and at what frequency was a concern and Nantes Metropole made the request not to store the information this way in the Urban Platform.

As a result, the users' "anonymous identifiers" are stored in the Urban Platform at a monthly level, in the form of an observation unrelated to the actual charging sessions (which are the ones to contain the precise information).

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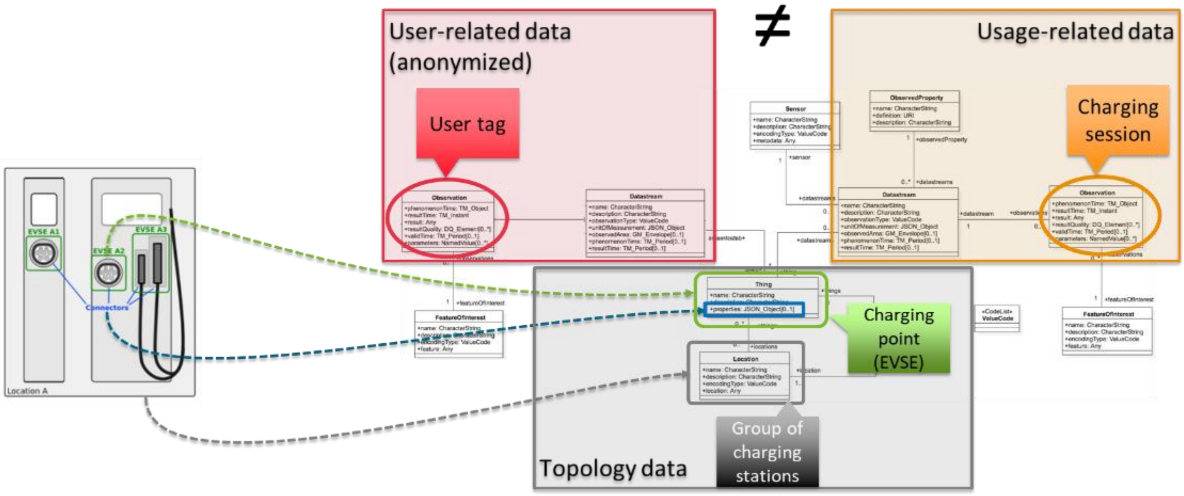


**Figure 27: GDPR concern in modelling observation data**

## 4.4 Charging points for e-bikes

### 4.4.1 Number and localization

As mentioned above, sockets allowing cyclists to recharge batteries of their e-bikes are installed on specific spaces dedicated to bicyles in car parks, in bike-parks located near Park-and-Ride parkings, as well as in individual boxes on public space. The following tables show the number and localization of socket that have been installed yet.

Sockets in car parks:

**Table 8: Number (July 2019) of charging points for e-bikes in Nantes car parks**

| Parkings | Perimeter | Number of bike parking spaces | Number of sockets for e-bikes | % (regarding total number of bike parking spaces) |
|---|---|---|---|---|
| DECRE-BOUFFAY | City center | 70 | **7** | 10% |
| GRASLIN | | 25 | **4** | 16% |
| TALENSAC | | 43 | **4** | 9% |
| TOUR BRETAGNE | | 85 | **8** | 9% |
| COMMERCE | | 72 | **10** | 14% |
| FEYDEAU | | 26 | **3** | 12% |
| **Total** | | **321** | **36** | **11%** |

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| | | | | |
|---|---|---|---|---|
| CITE DES CONGRES | West Center | 29 | **4** | 14% |
| MEDIATHEQUE | | 86 | **8** | 9% |
| ARISTIDE BRIAND | | 0 | | |
| LES MACHINES | | 64 | **0** | 0% |
| DESCARTES | | 30 | **5** | 17% |
| **Total** | | **209** | **17** | **8%** |
| CATHÉDRALE | | 67 | **7** | 10% |
| **TOTAL "heart of urban area"** | | **597** | **60** | **10%** |
| GARE CHÂTEAU | Railway station | 358 | **30** | 8% |
| GARE SUD 4 | | 50 | **3** | 6% |
| GARE SUD 3 (Ilot Jallais) | | 86 | **10** | 12% |
| GARE SUD 2 (5B) | | 215 | **8** | 4% |
| **Total** | | **689** | **49** | **7%** |
| **TOTAL** | | **1286** | **109** | **8%** |

**Table 9: Number (in July 2019) of charging points for e-bikes installed on public space (bike-parkings and individual boxes)**

| Public space | Number of bike parking spaces | Number of sockets for e-bikes | % (regarding total number of bike parking spaces) |
|---|---|---|---|
| Véloparc Ranzay | 24 | 4 | 17% |
| Véloparc Haluchère Nord | 24 | 4 | 17% |
| Véloparc Haluchère Sud | 18 | 4 | 22% |
| Véloparc Gare de Thouaré | 12 | 4 | 33% |
| Véloparc Marcel Paul | 24 | 4 | 17% |
| Véloparc Gréneraie | 20 | 4 | 20% |
| Véloparc Pirmil | 20 | 4 | 20% |
| Véloparc Gare Bouaye | 12 | 4 | 33% |
| Véloparc Babinière | 24 | 4 | 17% |
| Véloparc La Chantrerie | 12 | 4 | 33% |
| Véloparc Pont rousseau | 20 | 4 | 20% |
| Véloparc Frêne Rond | 10 | 4 | 40% |
| Véloparc Gare de Vertou | 15 | 4 | 27% |
| **Total Véloparcs** | **235** | **52** | **22%** |
| **Box individuels** | **62** | **62** | **100%** |

To this day, 225 sockets have been installed. In a short term, it is planned to implement 150 new bike parking spaces in individual or collective boxes, and 10% of them will have sockets for e-bikes. In a longer term (2024-2025), between 1,100 and 1,500 bike parking spaces will be deployed in the new Gare Sud car park and about 150 of them will be equipped with electric sockets.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

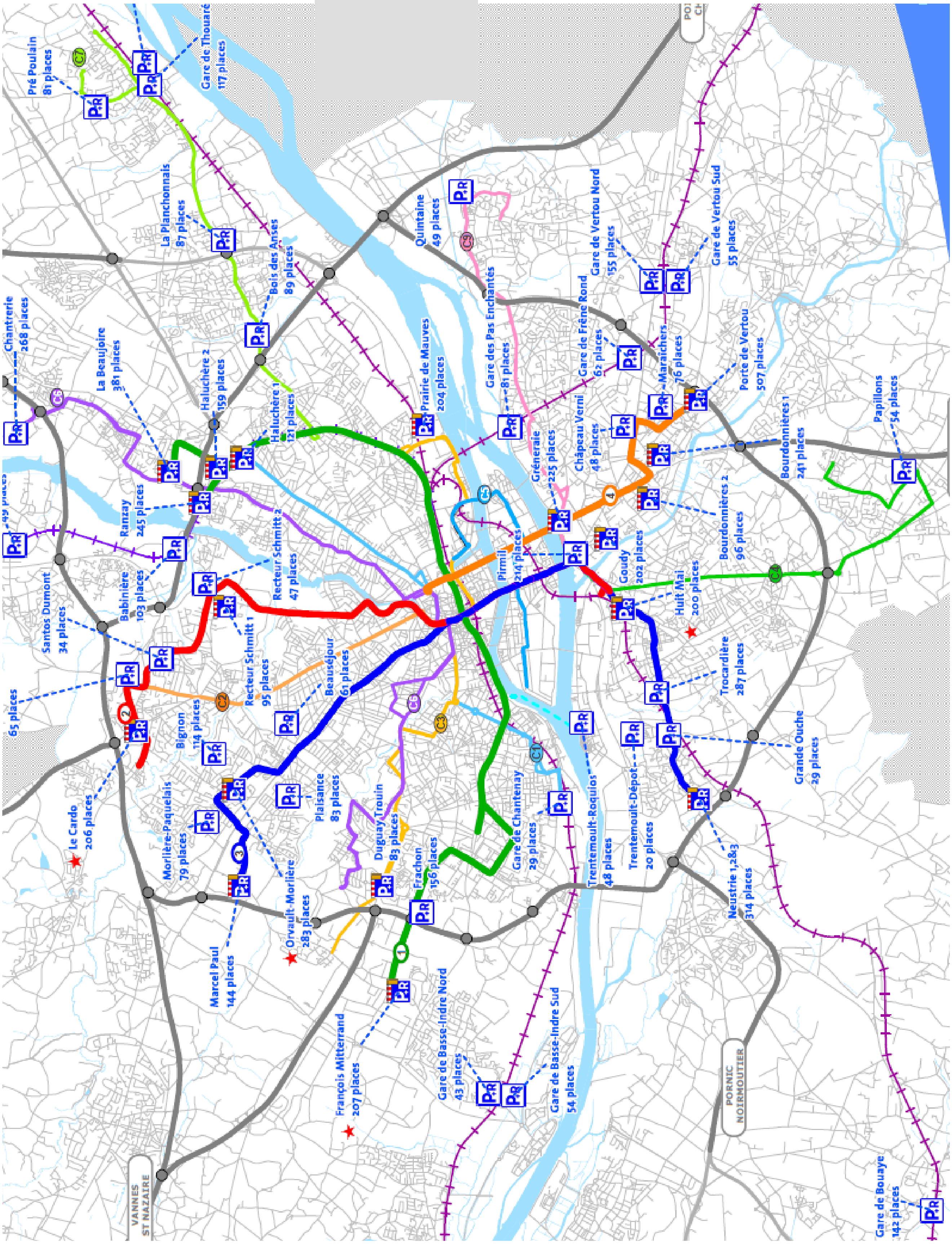


Figure 28: Localization of park-and-ride (P+R) parkings

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

### 4.4.2 Description of the implemented e-bike sockets and of their functionalities

Charging points for the e-bikes batteries are traditional domestic sockets (E / F type). Access to these sockets is free when users park their bikes in equipped parking spaces. For those installed on public spaces, the sockets are:

- Either in key lockers located in collective bicycles shelters (controlled access to these bike parks may be charged or not). In this case users only have to lock the lockers to secure their batteries
- Or in individual parking boxes (which are individual bike shelters: access is free, and users can secure the boxes with padlock or bike locks).

Because electric sockets are like household ones, they are not connected and cannot be managed.



**Figure 29: Pictures of 2 bikes park solutions (individual box and collective shelter) equiped with sockets for e-bikes**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.


**Figure 30: Collective bike shelters with secure lockers (in wich it is posible to recharge batteries)**


**Figure 31: Individual boxes with electric socket inside**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

# 5. Autonomous shuttle experiment

This section deals with the presentation of the autonomous shuttle experiment led by Nantes Métropole during the spring of 2019. This experiment was a première since it featured a three-dimension innovation: the vehicle, the environment sensing and the energy. In addition, the autonomous vehicle was operated on open roads, within a general traffic flow and it faced different technical difficulties to handle such as going through intersections.

## 5.1 History

### 5.1.1 Project timeline

As mentioned earlier, Nantes Métropole is a Public Institution of Intercommunal Cooperation (EPCI), i.e. the association of several (twenty-four in the case of Nantes Métropole) municipalities to develop and lead together a joint project of sustainable development of their territory. To help local companies to develop innovative initiatives, Nantes Métropole has created the “Nantes City Lab” in 2017. The Nantes City Lab offers a team that facilitates and accelerates innovations and it provide access to the Métropole territory as a test field. This service is open to start-ups, Small and Medium Enterprises, large groups, researchers, universities and associations looking for an urban laboratory to test their project.

In September 2017, a consortium of companies composed by SEMITAN, EDF (Electricité De France), Lacroix City, Charier and ID4Car suggested to Nantes City Lab experimenting for a year a full electric autonomous shuttle, starting from April 2018. This shuttle allows autonomy along three directions:

1. the driving autonomy since the shuttle is a driverless vehicle (even if there is still an operator on board as required for safety reasons);
2. the energetic autonomy with a solar road whose goal is to provide with enough electricity to compensate the shuttle consumption;
3. the autonomy in terms of sensing the surroundings thanks to:
    - vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communications, which are allowed by road side units;
    - the automatic detection of people waiting at the stations.

Nantes Métropole approved this demonstrator project on December 11, 2017 and made its territory available to the different companies in order for them to be able to have their experiment confront a real environment.

In France, the Ministry in charge of Transport (Ministère de la Transition Ecologique et Solidaire – MTES) is the only one in charge when it comes to granting the right to vehicles with self-driving capabilities to circulate on public roads. Such authorizations are delivered for a specific period and for identified road networks, after a careful analysis of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

applicant projects. The application has to describe the experiment and the experimental conditions, the vehicle(s), the transport service if any, the security instructions, the cybersecurity and the involved partners. The French legal framework is defined by the Ordonnance n°2016-1057 of August 3, 2016, by the Decree n°2018-211 on March 28, 2018 and by the Decree made on April 17, 2018 about the experimentation of vehicles with partial or total delegation of driving on public roads. SEMITAN presented the project for Nantes and was granted a Ministry agreement n°2018-11 on May 15, 2018 for the first experiment and then agreement n°2019-02 on January 25, 2019 for the second experiment.

After getting the agreement by the French Ministry in charge of Transport, the project leader has to apply for a special license plate number called “W garage certificate” to the French Home Office. This temporary number is only available for a civil year.

### 5.1.2 Goals

For Nantes Métropole, this project aims at testing a new means of public transportation with associated innovative equipment, having in mind to add it to its mobility offer for short-distance needs. The goal of the experiment was to get a precise idea of the abilities of this type of new vehicle and equipment.

### 5.1.3 Technical choices

#### 5.1.3.1 Autonomous shuttles

There were very few manufacturers on the market having operational autonomous vehicles available at the time. At the time, the consortium looked for a vehicle able to transport more than four passengers on a regular public transport service.

According to the SAE definition, there are six levels of driving autonomy (see Figure 1Figure 32):

- Level 0: there is no automation at all. The driver is responsible for the monitoring of the driving environment, for the execution of steering and acceleration or decelerations or for all the dynamic driving tasks.
- Level 1: there is a driver assistance by the system that can act on some specific driving-mode situations to help the driver for steering or acceleration / deceleration manoeuvres.
- Level 2: there is a partial automation. The steering and / or acceleration / deceleration are executed by the system and no longer by the driver.
- Level 3: there is a conditional automation meaning that the system monitors the driving environment, can execute steering and/or acceleration/deceleration but the human driver still has to respond appropriately to a request to intervene.
- Level 4: this is a high automation stage since the dynamic driving tasks are performed by the system in some specific situations.
- Level 5: there is a full automation. The system is able to cover by itself all driving modes in any situation. A human driver is no longer required.

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Currently, the available autonomous shuttles are at Level 3 or 4.

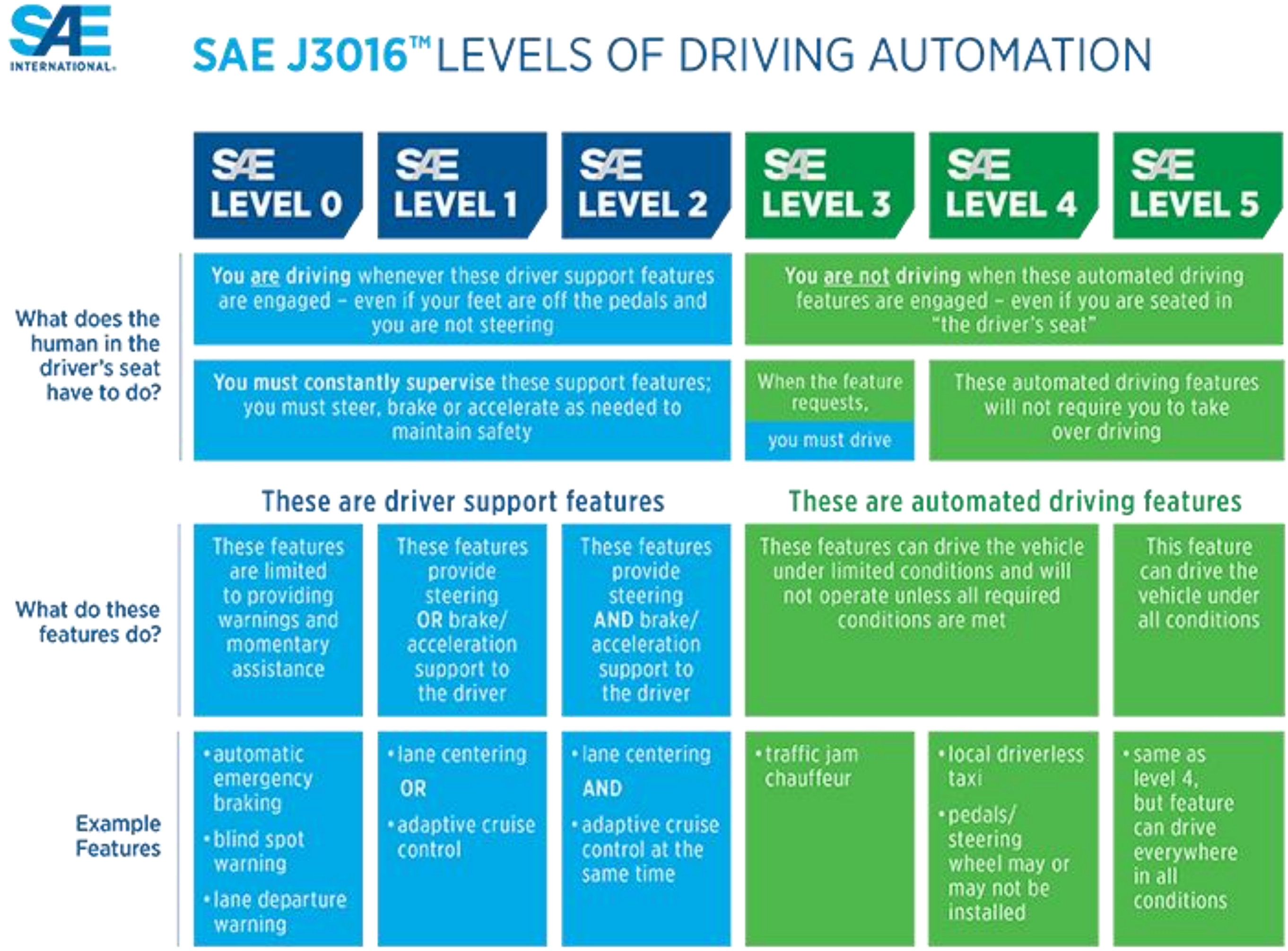


**Figure 32: Levels of autonomous driving (Source: SAE website)**

Among the existing solutions, there were mainly four companies dedicated to autonomous shuttles. Three of them are based in France:

- Navya presented its “Arma” shuttle in 2015 and started operations in Sion, Swiss in June 2016. The vehicle has been renamed AUTONOM SHUTTLE in November 2017. More details are provided in the following.
- EasyMile created in 2014 and deploying its “EZ10” autonomous vehicle since 2016. This shuttle has a capacity of 15 passengers.
- Lohr, which announced the “i-Cristal” shuttle together with Transdev in December 2017 and started operations in late 2018. The shuttle can welcome on board 16 passengers.

The fourth company, 2GetThere is a Dutch company part of German ZF Group. 2GetThere was involved in autonomy projects since 2000’s. It had two autonomous shuttles:

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- PRT standing for Personal Rapid Transit is a 4-seated-passenger vehicle that operated at Masdar City, Abu Dhabi, United Arab Emirates, since November 2010;
- GRT, for Group Rapid Transit, is a 22-passenger (8 seated, 14 standing) shuttle.

The consortium selected the French company Navya, based near Lyon. The Navya autonomous shuttles are already being tested in different places all around the world. EDF, member of the consortium, already deployed six AUTONOM SHUTTLES for a last-mile drive of its employees on the site of the nuclear plant of Civaux, in 2016. Other examples in France include:

- NAVLY at Lyon where two "Autonom Shuttles" are operating on a 1.3-kilometer-long route with five stops the open road carrying people along the river on the Confluence's district, since September 2016. The NAVLY trial is led by Navya and Keolis and is supported by The Métropole de Lyon and Sytral responsible for the public transportation means in the Lyon Metropolitan area.
- In Paris area, three shuttles have been circulating all week long, every week since July 2017 in the business district of Paris La Défense. Ile-De-France Mobilités, Keolis and Navya led the trial.

Navya has also launched the "Autonom Cab" which is a fully electric robot-taxi for at most six seated passengers. It can operate at 50 km/h and reach 90 km/h as top speed.

#### 5.1.3.2 Navya autonomous shuttle

The "Autonom Shuttle" by Navya has the following technical characteristics:

- Capacity of fifteen passengers (11 seated and 4 standing)
- Dimensions: 4.75m long, 2.11m width, 2.65m high and an empty weight of 2.4 tons
- Full electric engine with a 15kW nominal power (25kW as a peak power) powered by a Lithium Iron Phosphate (LiFeP04) rechargeable battery pack with a theoretical capacity of 33 kW.h, a theoretical average autonomy of 9 hours and a charge duration at 90% of 4 hours (7.2 kW plug) or 8 hours (3.6 kW plug).
- A theoretical maximal operating speed of 25 km/h.
- Localization and obstacle detection:
  - Two 360° multi-layers lidars and six 180° monolayer lidars that map the environment and detect the obstacles.
  - Front and rear cameras
  - Wheels encoder and inertial unit for the odometry, which allows it to enhance the positioning precision
  - A GNSS with Real Time Kinematic technique to enhance the real-time precision of satellite-based positioning systems such as GPS, GLONASS or Galileo for a mobile unit. The precision goes from less than one centimetre to a few centimetres. This uses a base-station and a possible network of referenced stations. The mobile unit (here the autonomous shuttle) have to move in a validity area of a few kilometres to a maximal 10km distance.

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The company NeoTCapital owns the AUTONOM SHUTTLE used in Nantes (for both 2018 and 2019 experiments) and SEMITAN rented it during the experimentation.


**Figure 33: The autonomous shuttle stopped at a station during the second experiment**

**(Credit: Marie-Amélie Horvath)**

The AUTONOM SHUTTLE has two driving modes:

- A manual mode: the operator drives the shuttle using a keyboard or a joystick. It is usually the case after turning the engine on and during the warm-up, until the shuttle reaches its scheduled path. In case of problem or incident, either the system or the operator on-board can force the complete stop of the shuttle. Then, the operator has to override in manual mode to restart the trip.
- An autonomous mode: once the shuttle is on its scheduled itinerary, it can ride autonomously as long as it does not meet any obstacle or encounter any technical problem such as a GNSS signal loss or a sensor dysfunction.

#### 5.1.3.3 Security plan: on-board operators

Navya trained five drivers and two supervisors from SEMITAN to handle the shuttle in manual and autonomous modes, for security including for problems management and to give information to the passengers. The training includes a riding scenario in the shuttle with a Navya agent. A training certificate was delivered to the attendees to ensure that they were ready to drive the shuttle.

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On-board, the operators were responsible for:

- turning on the shuttle;
- driving manually the shuttle between its container and the terminus station;
- realizing a first trip without passenger to ensure the conformity of the itinerary;
- welcoming and providing information to the passengers;
- enforcing the security instructions, such as the maximal number of passengers, the use of the seatbelt and so on;
- ensuring the good behaviour of the AUTONOM SHUTTLE in autonomous driving mode;
- stopping the shuttle if needed;
- contacting Navya and/or SEMITAN supervisions if needed. To this aim, the operator had a mobile phone to reach Navya and a Portable Digital Professional Radio (kind of talkie Walkie with an emergency call) for the SEMITAN mission control ;
- saving information about the experiment, including the number of passengers, the events, the weather and so on.

#### 5.1.3.4 Photovoltaic road

One of the goals of the experiment was to achieve the energetic autonomy. As the autonomous shuttle is a 100% electric-powered vehicle, it was interesting to produce and store enough electricity to charge the Navya shuttle outside of its driving periods. The consortium involved a French major energy provider, EDF and a local public works company, Charier, in order to bring a technical solution to this energy purpose.

Charier has developed the concept of SOLIF®, which uses the road as an energy-harvesting surface. SOLIF® consists in flexible photovoltaic panels are directly set on the pavement. Only pedestrians and cyclists are supposed to walk or ride on the panels. The system is meant to be easy to install and to remove. Charier previously tested the SolaRoad system, which was designed for a bike path in Krommerie city, the Netherlands, by Ooms Company. SolaRoad uses large concrete slabs of 3.5 by 2.7 meters, 25 cm thick, covered with successive layers of rigid photovoltaic cells, glass and a crushed glass and resin coating. Nevertheless, due to their thickness and weight (more than 5 tons), theses slabs were not adapted to the Nantes experiment, where it was not possible to modify the existing surface. It was necessary to develop a specific solution for existing pavements equipment.

During the first experiment, 35 meters squared of photovoltaic cells were deployed. Thanks to the high precision of the shuttle positioning system, the vehicle can ride over the solar road without ever touching it. However, this experiment showed that complementary development was necessary in order to solve electrical and surface quality problems.

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**Figure 34: Picture of the shuttle and the SOLIF® solar road during the first experiment (Credit: Charier website [https://www.charier.fr/images/innovation/innovation_envir_navette.jpg](https://www.charier.fr/images/innovation/innovation_envir_navette.jpg))**

### 5.1.4 First experiment

#### 5.1.4.1 Quick description

The consortium led a first experiment in June 2018 on Loire wharfs, namely quai Marquis d'Aiguillon, between Carrière Miséry site and the Gare Maritime tramway station, at the occasion of "Complètement Nantes" event. The shuttle only circulated when people asked for it, thanks to a call button located in the bus shelters at the terminus stations.

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**Figure 35: Schematic view of the shuttle itinerary during the first experiment (Source: Google Maps)**

The shuttle circulated on a path outside of the general traffic flow. The shuttle used:

- A 400-meter-long section on the Loire wharf, which is a private road belonging to the Grand Port Maritime de Nantes-Saint Nazaire, only used by cyclists and pedestrians. This section is delimitated by a barrier that gave information to the shuttle about its state (open or closed) thanks to a Road Side Unit.
- A 260-meter-long corridor on a 2-by-2 road. This corridor used to be devoted to buses, cycles and taxis. It was specifically requisitioned for the autonomous shuttle on this occasion. While buses and taxis were shifted to the general traffic flow, a cycle and pedestrian lane has been created next to the road along the river wharves. To make the shuttle round-trips secure, the lane was separated from the general traffic flow by concrete pads at both extremities and by plastic markers all along its path.

As a result, during this first experiment, the AUTONOM SHUTTLE only came across pedestrians and cyclists. There were no road crossings or roundabouts to deal with. It had to deal with very few cars, those that were allowed to access and park in front of the two companies hosted in a former warehouse, on the first section of the shuttle itinerary.

#### 5.1.4.2 White walk

From May 29 to May 31, 2018, SEMITAN organized a three-day white walk for the autonomous shuttle. All the trained operators were involved. The shuttle ran on the itinerary under normal operating conditions without public

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passengers. No incident occurred, either in terms of road safety or in terms of cybersecurity. A potential conflict between the shuttle and cyclists was identified at some points that led to enforcing some barriers preventing cyclists to bike in this area.

#### 5.1.4.3 Teachings of the first experiment

This first experiment showed good results in terms of autonomous driving: it reached 1029 trips, with 934 kilometres travelled. It carried over 5,200 passengers in only 24 days of operation, with a peak at 814 passengers a day. The shuttle consumed an averaged 0.5 kWh/km. However, the shuttle had a mean velocity of 10 km/h and a top speed of 12.6 km/h, which was a bit disappointing for the consortium.

On the autonomy in terms of energy, the solar road did not produce as much electricity as expected. Indeed, only 38 kWh have been produced over the expected 200 kWh. This is due to the waterproofness of the photovoltaic cells coupled to the bad weather conditions in Nantes in June 2018. The experiment was a good experience and it allowed performing a new version of the material that has been later deployed on the second experiment.

On the security side, there were no accident affecting the road safety or involving people. For instance, the shuttle correctly slowed down in front of cyclists.
There was a material incident on June 22, 2018 at 4:40 pm: the barrier delimitating the private site of Grand Port Maritime de Nantes-Saint Nazaire closed on the shuttle due to a wind squall. The shuttle immediately stopped.
The operators also noticed three brutal braking of the shuttle:

- the first one was due to a pigeon
- a dog caused the second one
- a flying cardboard forced another braking

For the two first cases, the animals waited the last moment to move from in front of the shuttle because of the low speed of the vehicle. This slow-moving object seemed not to frighten them.
Heavy rains also disturbed the shuttle, generating small braking.

On the communication side, the equipment (made of one Road Side Unit, radars and V2X modules coupled with the automatic barrier) deployed by Lacroix City to augment the environment perception of the autonomous shuttle allowed to collect a lot of data that Lacroix group could use to learn a lot. No cameras have been deployed during this first experiment so there were no automatic detection and passenger counts at stations.

The operators and the passengers were enthusiastic about this experiment and they expressed both curiosity and interest.

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This first experiment also served to understand better the requirements of the French Ministry in charge of Transports. It helped to improve the second experiment concerning:

- The a priori preparation of the experiment:
    - Selection of the test site;
    - Risk analysis and list of solutions to reduce them.
- The exchanges during the experiment;
- The a posteriori reports on the experiment.

## 5.2 The test site

This section is devoted to the description of the site where the second experiment of the autonomous shuttle took place. As mentioned, this second experiment aimed at testing the behaviour of the shuttle in a more complex environment.

### 5.2.1 Description of the site

For the second experiment, the deployment was realized on open roads in the activity park close to Nantes Atlantique airport, near Composite and Ocean Technocampus, the Jules Verne Technological Research Institute (IRT) and Airbus factory plant. The selected use case was to transport people from different companies in the airport activity area to a Inter-Company Restaurant (RIE for French “Restaurant Inter-Entreprises”), back and forth, during the meridian break i.e. between 11:30 am and 2:30 pm. The shuttle covered a 2.5 km long loop, serving three stations arranged for this occasion.

Along its itinerary, the shuttle crossed:

- One traffic light;
- Three roundabouts;
- Eight pedestrian crossings;
- One bike lane.

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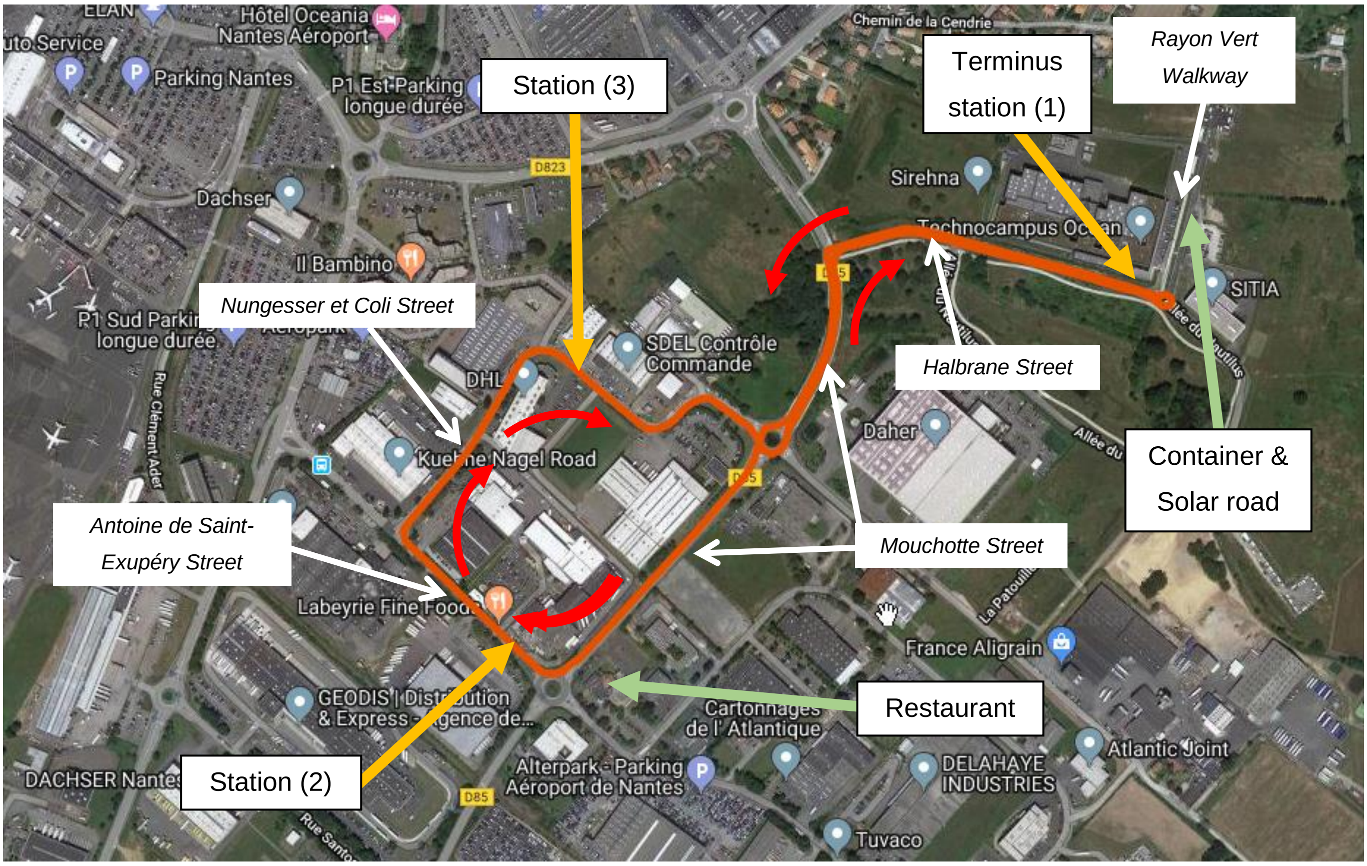


**Figure 36: Shuttle itinerary during the second experiment**

Outside of its operating period, the shuttle was parked in a closed container located on Rayon Vert Walkway (see Figure 36 and Figure 37).

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**Figure 37: The Navya shuttle and its container (Credit: Gilles FARGE, Nantes Métropole)**

### 5.2.2 Photovoltaic road

A new prototype of the SOLIF® solution was developed by Charier for this second experiment. A 25-meters-squared surface of photovoltaic panels was installed on Rayon Vert Walkway (see Figure 38). The panels consist in a thin surface of less than 1cm, including the glue. Each solar panel measures 115x81 cm, weights 3 kg and has a maximal electric output performance of 150 Watt-peak in Standard Test Conditions. The monocrystalline-silicon solar cells were provided by SunPower Company and were protected by a crushed-glass layer. Only pedestrians and bicycles were allowed to walk or ride on it. The surface was designed in order to match with adherence expectation of Nantes Métropole. The SOLIF® solution performs a skid resistance of 54 at the SRT pendulum.

The electricity produced during the day was reinjected in the EDF electric network through an inverter and then, the autonomous shuttle was recharging during the night by connecting to the EDF network. There is no local storage with batteries.

It was estimated that the energetic return period, say the time interval necessary to produce enough electricity to compensate the energy consumed for the making and installation of the system, is approximately of 4 years and a half.

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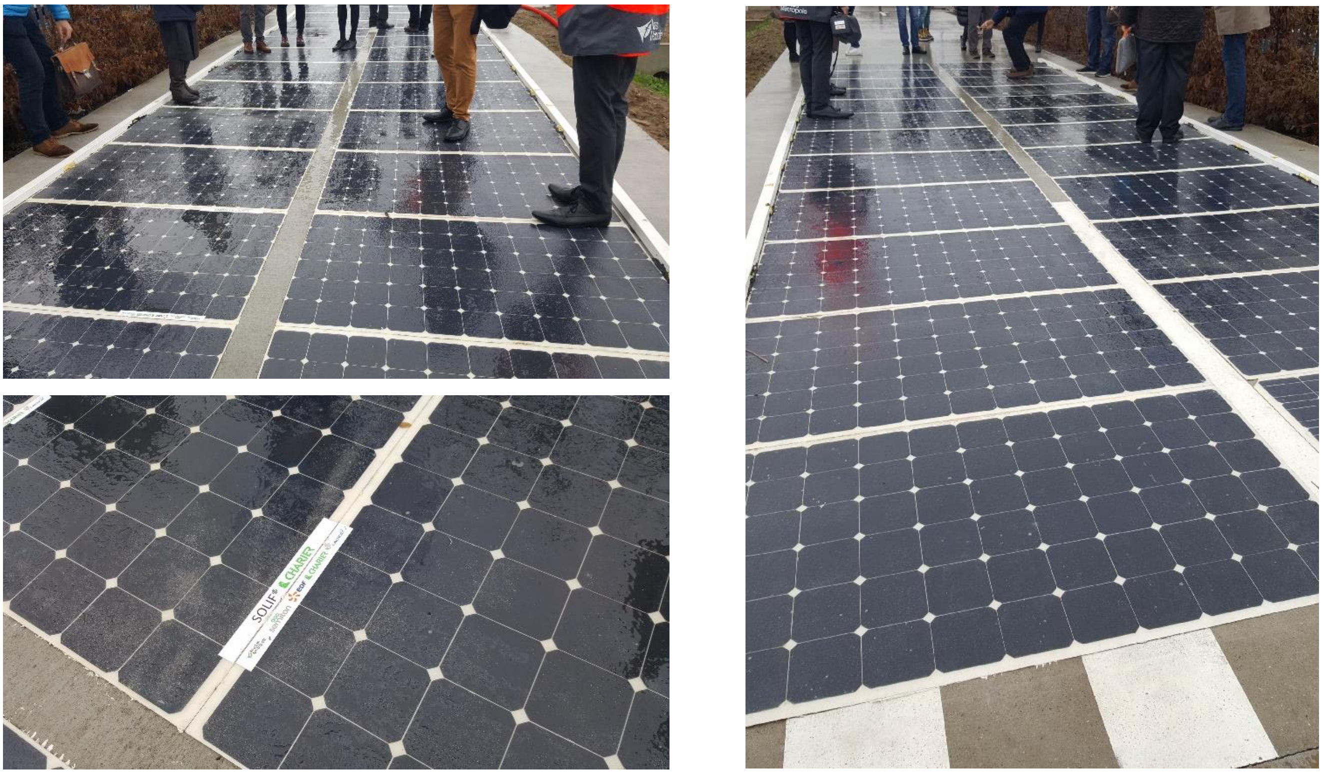

**Figure 38: Pictures of the photovoltaic road on Rayon Vert Walkway (Credit: Marie-Amélie Horvath)**

### 5.2.3 Preparation of the autonomous shuttle

The white walk was conducted from February 4 to February 28, 2019. It aimed at testing:

- The operating speed profiles,
- The shuttle trajectory,
- The emergency stops along the path,
- The shuttle behaviour under the normal operating conditions without public passengers.

Regarding the speed profiles, different stretches were defined according to the desired maximal speeds going from 10 to 25 km/h (see Figure 39). The speeds were decided by Navya relatively to safety and dynamical conditions required for instance for decelerations upstream intersections and stations. The shuttle manufacturer, Navya was in charge of the tests since it is the only one able to change the settings in the vehicle software. A maximal speed of 18 km/hr was programmed on Halbrane and Mouchotte Streets. In roundabouts and traffic-light crossroads, the maximal speed was set between 9 and 10 km/hr.

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**Figure 39: Speed profiles for the autonomous shuttle (Source: SEMITAN)**

### 5.2.4 Adaptation of the infrastructure

#### 5.2.4.1 Maximal speed limits

Before January 2019, the speed was limited to 80 km/h for roads outside of the agglomeration (say, on Halbranne Street), while it was limited at 50 km/h inside the agglomeration (all the other roads). In January 2019, the maximal speed was reduced to 50 km/h on all the roads in the zone, for sake of safety and homogeneity. Then, this speed limit was put to 30 km/h for all the roads concerned by the passage of the Navya shuttle and only during the experiment. This speed limit was selected to minimize the speed difference between vehicles and the autonomous shuttle.

#### 5.2.4.2 Overtaking regulation

In a first time, the continuous lines on the two-way roads, notably on Mouchotte Street, have been turned into discontinuous ones to allow overtaking manoeuvers. However, during the white walk of the autonomous shuttle, it was noticed that overtaking created too many brutal braking of the shuttle. Indeed, the sensors of the shuttle detected the overtaking vehicles and forced the shuttle to stop due to a potential danger. Hence, the discontinuous lines have been re-changed immediately into continuous lines to avoid overtaking manoeuvers.

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#### 5.2.4.3 Control of the troublesome parking

On December 3, 2018, Nantes Métropole technical services set wooden blocks along the pavement of Nungesser et Coli Street. These blocks aim at avoiding troublesome parking on the sidewalk that could overtake on the road and might block the shuttle. Indeed, the shuttle has a programmed path, similar to a track, and cannot overtake an obstacle by itself. It requires the on-board operator to take control of the shuttle to overtake the obstacle. In order to minimize this kind of events, it was decided to avoid any troublesome parking along the path followed by the shuttle.

#### 5.2.4.4 Stations for passengers

For the needs of the experiment, three temporary stations have been built along the shuttle itinerary. These stations are respectively located (see Figure 36):

- In front of the Technocampus, on Halbrane Street;
- Close to the restaurant, at the angle between Mouchotte Street and Antoine de Saint-Exupéry Street;
- On Nungesser et Coli Street.

These stations have been uninstalled at the end of the experiment. Since they could be easily moved, these bus shelters could be re-used on other public transport lines in case of temporary perturbations, such as civil works.

At these locations, Lacroix City has added cameras for sake of automatic detection of passengers waiting at the stations (see Figure 40). The cameras were set on February 16 and parametrized on March 6. Until the end of March, a learning period has been observed. Photovoltaic panels alimented these cameras. The cameras provide also images that were used to attempt to count people going up and down in the shuttle at each station.

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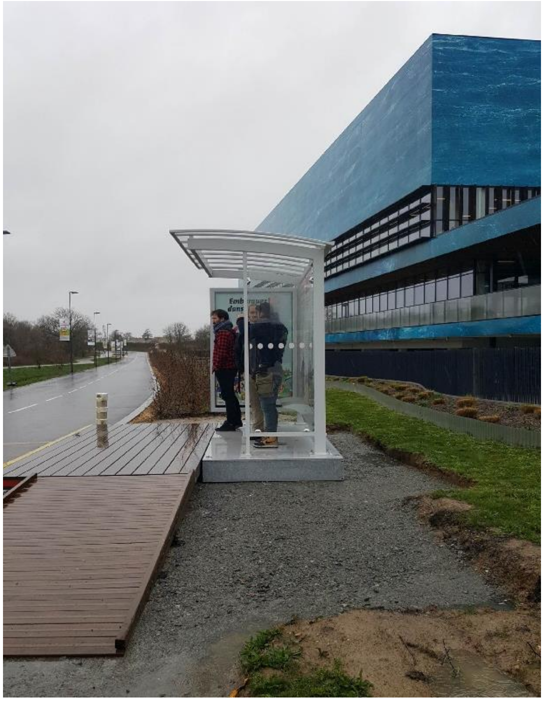

(a) Station in front of Technocampus on Halbrane Street

(b) Camera and its photovoltaic panel

(c) Station on Antoine de Saint-Exupéry Street, close to RIE

**Figure 40: Pictures of the temporary stations and their equipment (Credit: Marie-Amélie Horvath / Gilles Farge)**

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#### 5.2.4.5 Traffic light intersection

On December 6, 2018, a connected traffic signal was set at the intersection between Halbrane Street and René Mouchotte Street. This traffic light replaced a stop sign from road users at the end of Halbrane Street. The max speed on Halbrane Street was limited to 50 km/h. The traffic signal was connected thanks to a Road Side Unit that enabled to send information from and to the shuttle such as the colour of the light. In addition, the shuttle sent its position to require the signal to turn green when arriving.

In degraded situation, if the signal is off or in default mode (flashing orange), the priority rule is either given by panels fixed on the signals or by default, road users have to give the way on the right. Hence, the shuttle should stop when it left Halbranne Street and headed on Mouchotte Street as soon as vehicles arrived on its right.
Nantes Métropole tested this degraded situation. During the test, the shuttle refused priority to a motorist arriving to its right on Mouchotte Street. Following this incident, Navya modified the settings of the shuttle in order to comply with the degraded priority regime.

The pedestrians and cyclists did not have a call button at the traffic intersection, because by default the traffic light was green for the active modes of René Mouchotte Street, unless there was traffic coming out of the Halbrane Street. They could cross without signals, except when their signal was red if vehicles were coming out of Halbrane Street.

#### 5.2.4.6 Positioning helps

In order to allow a very precise geo-positioning, the shuttle uses its GPS-enabled (Global Positioning System) sensor and it uses a digital cartography of its environment made during its first rides on its itinerary. This cartography relies on the sensing of the shuttle environment by its Lidar sensors. In addition, the shuttle needs to identify some fixed points as landmarks near its path. In an urban environment, as it was the case during this second experiment, these landmarks are generally the facade of buildings or houses in the near vicinity of the road. However, when the buildings are too far from the road, the sensors of the shuttle cannot get a precise cartography and thus, needs some new landmarks. Hence, Nantes Métropole following a demand by Navya, decided to install a set of thirty-five kakemonos along the way, where the built surfaces were too far from the road. These kakemonos consist of big rectangular flags that were set on candelabra (see Figure 41). They also allowed giving information to people circulating there.

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**Figure 41: Pictures of the kakemonos (Credit: Cerema Ouest)**

Additionally, the shuttle needs a clear delimitation on the ground between the two ways of the road. Thus, on some roads in the experimentation area, Nantes Métropole has created or renewed some axial signalization. This has been done in particular on Halbrane Street and on Nungesser and Coli Street. It went together with the overtaking regulation.

#### 5.2.4.7 Other (civil) works

For the sake of the experiment, other works have been done along the shuttle path:

- The experiment implied a regular tree and vegetation pruning. Indeed, any branch too close to the road could be detected as a potential obstacle for the shuttle and might force it to a complete stop.
- On Rayon Vert Walkway:
  - Stakes have been added to the three accesses of the "green route" (the French "voie verte" dedicated to active modes, thus excluding motorized vehicles) on the entrances of the Ocean Technocampus in order to prevent the vehicles from coming to park there and to protect the photovoltaic panels.
  - In the North part of the "green way", close to the northernmost delivery entrance of Technocampus, the container housing the shuttle at night was placed on the "green way" and occupied the entire width. In order to restore a route to cyclists, Nantes Métropole has provided cyclist access to the tarred way protected by concrete cubes.
- On Halbrane Street: Nantes Métropole set a mini roundabout passable to allow the shuttle to turn back to its terminus and return to its starting position.
- On Mouchotte Street:

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- Nantes Métropole neutralized the possibility for the active modes (i.e. including pedestrians and cyclists) to cross Mouchotte Street near Halbrane Street (in the place provided for this purpose), 15 meters at the South of the crossroads between Halbrane and Mouchotte Streets. This has been done because of the incompatibility of the positioning of this crossing with the positioning of the lights of the temporary fire station set up for the occasion. This point was pointed out thanks to the exchanges with the Ministry in charge of Transportation.
- To allow cyclists to access the Technocampus Ocean from Aviation Street, Nantes Métropole indicated at the North side Street entrance that cyclists were invited to pass on the East side of the Street to access the Technocampus, crossing the beginning of the Street via the pedestrian crossings.
- Nantes Métropole also posted a signal at the North pedestrian crossing of the roundabout between Mouchotte and Nungesser and Coli Streets, to guide pedestrians wishing to go to the Technocampus Ocean on the East side of Mouchotte Street.
- To facilitate the perception by the shuttle of the presence of pedestrians at the crossroads between Mouchotte and Halbrane Streets, Nantes Métropole deposited a stake located on the middle of the South round of the sidewalk at the intersection between Mouchotte and Halbrane Streets. Indeed, at this junction, the shuttle had to give way to the pedestrians and cyclists who circulated along Mouchotte Street, even though the shuttle had a green light to turn right.

In addition, Nantes Métropole has installed some specific vertical signage to warn road users that they entry or exit of an experimental zone with an autonomous vehicle (see Figure 42).


(a) Panel at the entrance of the experimentation zone (English translation: "Experimentation of an autonomous shuttle. Caution. From 15/01/2019 to 30/04/2019")


(b) Panel at the exit of the experimentation zone (Translation: "End of experimentation zone of an autonomous shuttle")

**Figure 42: Information panels for road users (Credit: Cerema)**

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# 6. Monitoring and evaluation

## 6.1 Monitoring and evaluation presentation

The monitoring process is an essential part of the project. It provides the necessary raw material for carrying a precise evaluation of this project, keeping track of performance, further helping to understand the impacts one intervention can bring; also to relate to the city scale.

As part of WP5 dedicated to the monitoring, some work has already been done and preparation was undertaken to be ready for M36, and to prepare for the monitoring.

The WP5 work is still ongoing, and projections are subjected to change; but first milestones have undoubtedly been reached upon the common work of WP5 T5.1, T5.2 and T5.3, such as the set of monitoring key performance indicators (KPIs), shared between the three lighthouse cities and based upon reference sources (“SCIS” or “CITYKEYS” to name a few).

As for this deliverable and at times of writing, monitoring schemas and refined sets of key performance indicators KPIs have been consolidated to prepare the monitoring implementation for each action.

These documents are developed as part of the WP5 T5.3 for which an interim version of the deliverable D5.3 is due by M36, and the final one by M48; it is likely, therefore, they could be updated with a few changes.

## 6.2 List of KPIs and monitoring schemas

In mySMARTLife project, a list of shared indicators has been established so that the actions and their impacts may be compared from one city to another. These indicators will be centralised in the Urban Data Platform. Below are the monitoring tables which explain, for each KPI defined to evaluate mobility actions, how they will be calculated, with formulas, units, KPI sources and more information on the integration with the mySMARTLife ICT ecosystem.

As mentioned above, these tables can still be updated in the coming months, as they are part of WP5 T5.3 and for which the final version of the deliverable is due by M48.

In these tables, yellow rows highlight primary indicators, which are based on the collected data; while blue rows show the secondary indicators which can be calculated straight from the primary KPIs; the green rows colour, finally, the secondary indicators for which a human evaluation is required.

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Finally, from the common KPI list shared with the three cities, Nantes' stakeholders from monitoring & the Urban Platform have worked together to bring a systemic KPI integration framework into Nantes' Urban Platform. This is described more into details in the Urban Platform deliverable (D2.8) in the "ontology" chapter. A KPI column has finally been added to assess of this strong link.

### 6.2.1 E-buses and charging stations for e-buses

SEMITAN has set up a monitoring scheme for both the eBusways and the charging substations, thanks to a data feedback from the equipment to the central management centre. This monitoring has two main objectives:

1) To ensure a real-time supervision of the bus line by knowing for instance:
    - The state of the battery charge;
    - If the bus is currently charging at a station or not;
    - The eventual default codes corresponding to warnings displayed on the driver dashboard;
    - The energy flux at each substation.
2) To allow for a posteriori studies such as:
    - Statistics on the travelled distance, the number of passengers and the eventual breakdowns;
    - The monitoring of the battery lifetime;
    - Analyses for improving the maintenance of the equipment.

The data are collected and stored in each bus and then send to the server by Wifi connection when the bus is parked at the CETEX. The available data represent approximately 2.7 Go per bus and per day. This huge quantity needs to be treated and carefully selected.

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**Table 10: List of KPI for the evaluation of the eBusway**

| Indicator | Type | Monitored? | Formula | Unit | Source | Urban Platform | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Service | Integration | Open Data |
| Annual distance travelled | Primary | Monitored | # | km/year | Sensors | No | Yes | Yes |
| Annual energy consumption | Primary | Monitored | # | kWh | Sensors | No | Yes | Yes |
| Annual energy consumption per annual distance travelled | Secondary | Monitored | M9 / M5 | kWh / km | Calculation | No | Yes | Yes |
| Average number of passengers per working day | Secondary | Mixed | Average(number of passengers per working day for all working days of the year) | # | Evaluation | No | Yes | Yes |
| Availability rate of e-buses | Secondary | Monitored | Number of days of availability / number of days of normal use | % | Evaluation | No | Yes | Yes |
| Percentage of e-buses equipped with data collection | Secondary | Monitored | (Number of e-buses equipped with required equipment for data collection for KPI's) / (Number of e-buses available) x 100 | % | Evaluation | No | Yes | Yes |
| Annual CO2 emissions saved | Secondary | Simulated | Percentage reduction in direct (operational) CO2 emissions achieved by the deployed eVehicles during a period of one year. | t CO2 / year | Evaluation | No | Yes | Yes |
| Annual number of passengers | Primary | | Number of passengers/users travelling during a year for each type of vehicle | # | | No | Yes | Yes |
| Annual number of trips | Primary | | Total number of trips done by the e-vehicle (s) during a year | trips/year | | No | Yes | Yes |
| Average distance travelled by trip | Secondary | | Average distance travelled by the e-vehicle (s) in each trip | km/trip | Calculation | No | Yes | Yes |
| Annual energy delivered by each charging point | Primary | Monitored | # | kWh / year | Sensors | No | Yes | Yes |
| Number of charges per charging point per year | Primary | Monitored | # | # | Sensors | No | Yes | Yes |
| Annual energy delivered by charging points | Secondary | Monitored | Sum of M17 for all charging points over one year | kWh / year | Calculation | No | Yes | Yes |
| Average energy delivered per charging operation and per charging point | Secondary | Monitored | For each charging point : M17 / M20 | kWh | Calculation | No | Yes | Yes |
| Station uptime per year | Primary | Monitored | Amount of time that the charging points are functioning properly (e.g. withouth any power interruptions) | % | Evaluation | No | Yes | Yes |
| Percentage of electricity supplied to charging stations by renewable energy sources compared to the total energy suuplied | Secondary | Simulated | Percentage of electricity supplied by renewable energy sources in the total annual energy delivered by the charging points | % | Evaluation | No | Yes | Yes |

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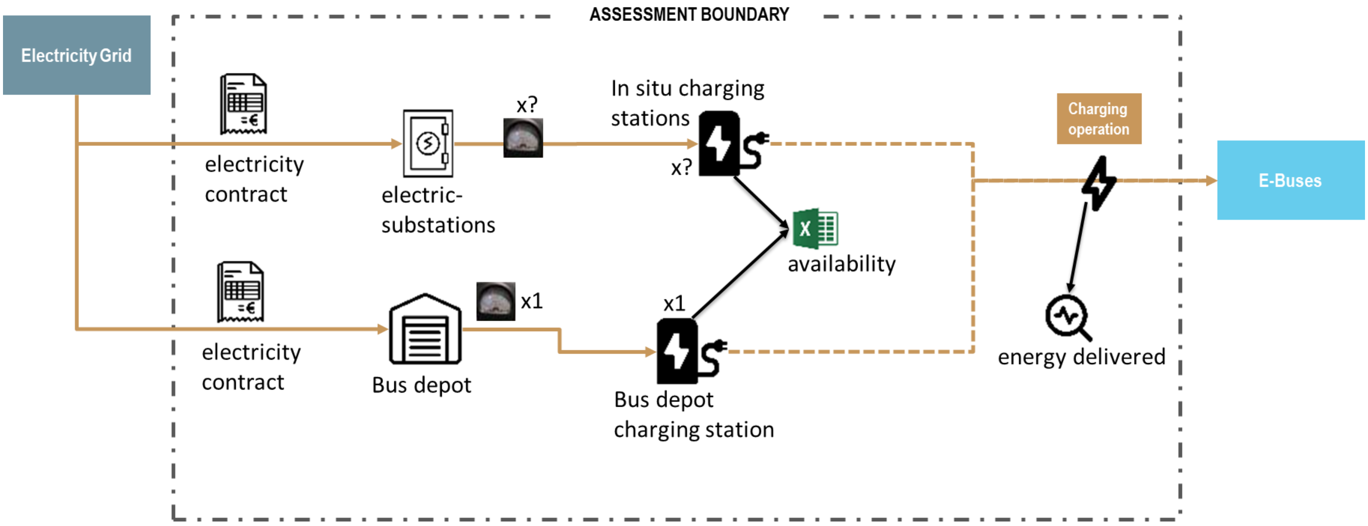


**Figure 43: E-buses monitoring schema**

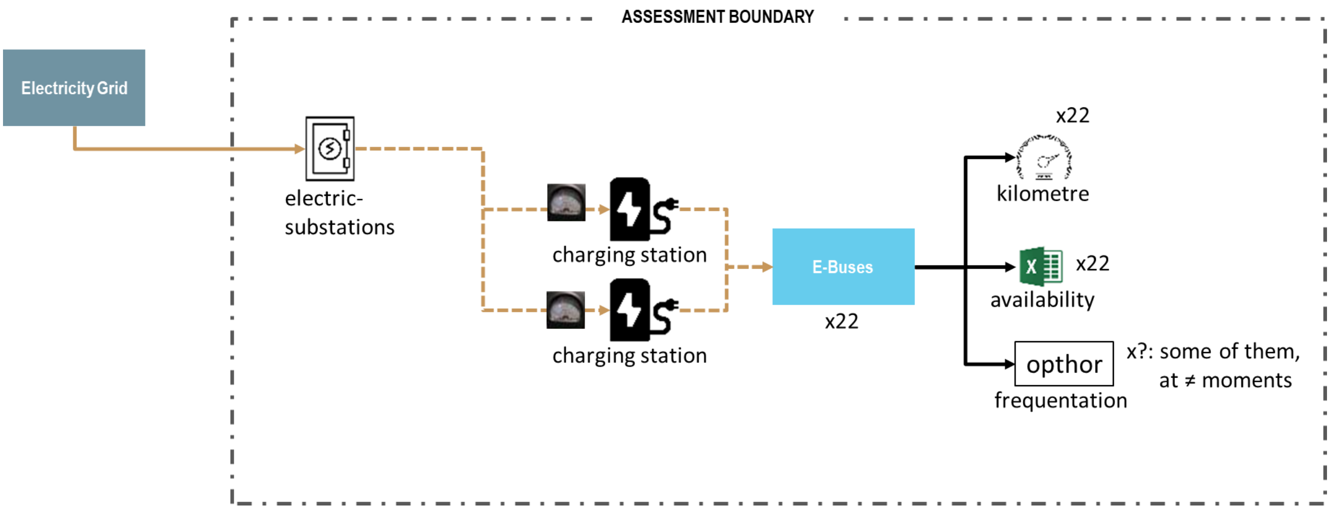


**Figure 44: Opportunity charging for e-buses monitoring schema**

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### 6.2.2 Charging stations for individual e-vehicles

**Table 11: List of KPI for the evaluation of charging stations for individual cars**

| Indicator | Type | Monitored? | Formula | Unit | Source | Urban Platform | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Service | Integration | Open Data |
| Annual energy delivered by each charging point | Primary | Monitored | # | kWh / year | Supervision system | Yes | Yes | Yes |
| Number of charges per charging point per year | Primary | Monitored | # | # | Supervision system | Yes | Yes | Yes |
| Total operating time for charging operations | Primary | Monitored | For each station and per year: (Total hours of charging) / (hours in a year; or number of expected hours of functioning) x 100 | hours | Supervision system | Yes | Yes | Yes |
| Average duration of charging operations | Secondary | Monitored | M21 / M20 | hours | Supervision system | Yes | Yes | Yes |
| Number of different users per year | Primary | Monitored | | # | Supervision system | Yes | Yes | Yes |
| Station uptime per year | Primary | Monitored | (Total hours of proper functioning) / (hours in a year; or number of expected hours of functioning) x 100 | % | Supervision system | Yes | Yes | Yes |

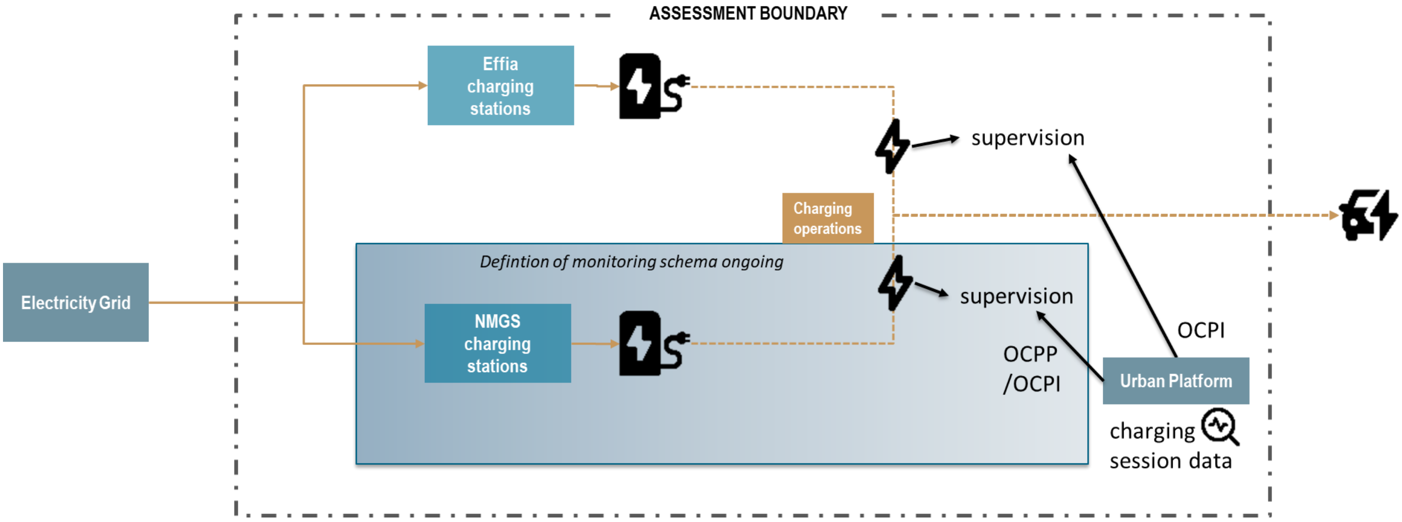


**Figure 45: Smart charging stations monitoring schema**

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### 6.2.3 Autonomous shuttle and solar road

**Table 12: List of KPI for the evaluation of the autonomous shuttle and the solar road**

| Indicator | Type | Monitored? | Formula | Unit | Source | Urban Platform | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Service | Integration | Open Data |
| Annual number of passengers | Primary | Monitored | Number of passengers/users travelling during a year for the autonomous shuttle | # | Experimentation report | No | Yes | Yes |
| Average number of passengers per working day | Primary | Monitored | Average of passengers travelling each working day | # | | No | Yes | Yes |
| Annual number of trips | Primary | Monitored | Total number of trips done by the autonomous shuttle during a year | trips/year | | | | |
| Annual distance travelled | Primary | Monitored | Total distance travelled by the autonomous shuttle during a year | km/year | | No | Yes | Yes |
| Average distance travelled by trip | Secondary | Monitored | Average distance travelled by the autonomous shuttle in each trip | km/trip | Calculation | | | |
| Availability rate of e-buses | Primary | Monitored | Rate of days in which the autonomous shuttle is driving | % | Experimentation report | No | Yes | Yes |
| Percentage of e-buses acquiered that have equipped for data collection | Primary | Monitored | Ratio of autonomous shuttles with data collection equipments | % | | No | Yes | Yes |
| Annual energy consumption | Primary | Monitored | Energy consumption of the autonomous shuttle during a year | kWh/year | | No | Yes | Yes |
| Annual energy consumption per annual distance travelled | Secondary | Monitored | Energy consumed by the autonomous shuttle to cover the kilometers travelled during a year | kWh/km | Calculation | No | Yes | Yes |
| Annual CO2 emissions saved | Secondary | Monitored | Percentage reduction in direct (operational) CO2 emissions achieved by the deployed autonomous shuttles during a period of one year. | tCO2/year % in tonnes of CO2 | Evaluation | No | Yes | Yes |
| Number of incidents and trafic accidents where the shuttle was involved | Primary | Monitored | Number of incidents and trafic accidents where the shuttle was involved | # | Experimentation report | No | Yes | Yes |

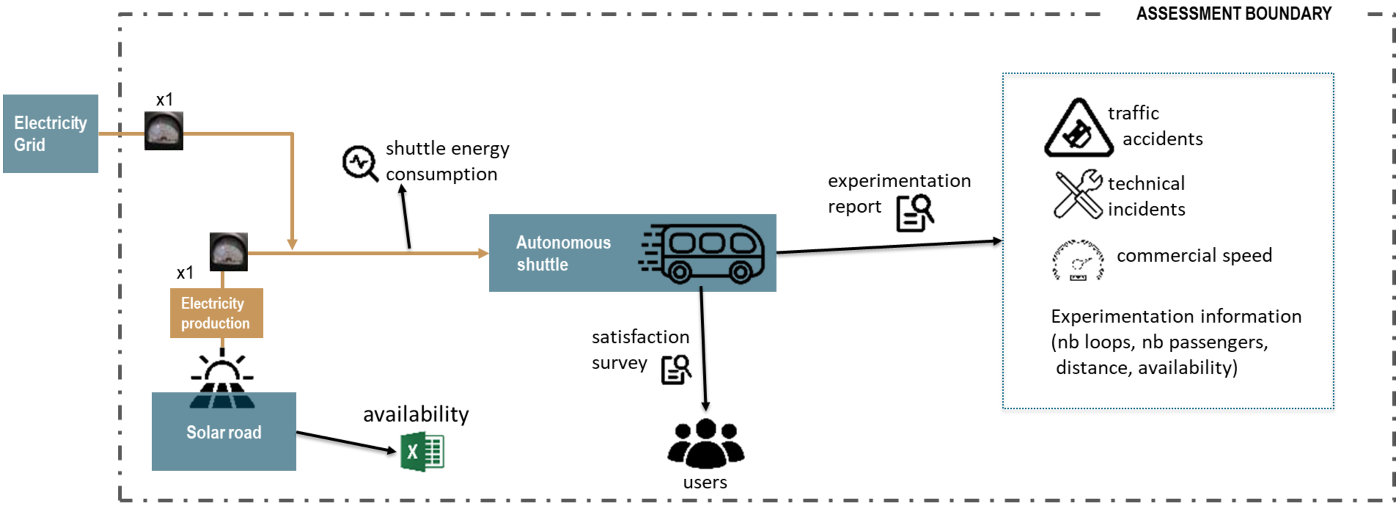


**Figure 46: Autonomous shuttle and solar road monitoring schema**

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## 6.3 Evaluation of the autonomous shuttle experiment: first elements

Overall, this second experiment proved positive. Among the points of satisfaction, note the crossing of intersections, either the three roundabouts or the traffic intersection.

On the other hand, the slow speed of the shuttle has caused many problems and discomfort for the occupants of the shuttle, including for the on-board operators. Indeed, this low speed seems to not have been sufficiently well accepted by other users. This resulted in dangerous behaviour, with the passing of the shuttle even on road sections where it was forbidden. These behaviours proved to be harmful since the overtaking caused abrupt shutdowns of the shuttle and therefore even more impatience among the users blocked behind the shuttle.

Other negative points related to the great prudence of the shuttle, include stops due to vegetation growth or troublesome parking and the need to resume driving in manual mode. This limits the driving autonomy of the shuttle For a widespread use of the shuttle, its insertion in roundabouts with higher traffic volume or with higher traffic speeds is still an open question.

### 6.3.1 Partners' satisfaction

The experiment of the shuttle and of the solar road has been a great opportunity for the consortium to understand this new mobility technology and to identify the current Technology Readiness Level (TRL) of the autonomous vehicles for public transport. The first experiment (on the Loire's quays) has allowed learning a lot about the shuttle in a simplified context but it provided also a better understanding of the Ministry requirements in terms of application form. The second experiment has permitted going deeper in the knowledge of the technical capacities of the shuttle in a more complex environment and testing an improved prototype of the solar road. It has been also the occasion for each partner to focus on how it could benefit from this new expanding market. The project ended up with an overall satisfaction from partners about the gained experience.

It is interesting to note that the partners of the consortium are engaged in a new project for testing another autonomous shuttles between the terminus station of tramline 3 (La Neustrie) and Nantes Atlantique airport from 2019 to 2021. This project is part of the laureates from the call for projects "Expérimentation du Véhicule Routier Autonome" (French for Testing of autonomous road vehicles) launched in 2018 by the French Ministry in charge of Transports.

### 6.3.2 Technical evaluation

#### 6.3.2.1 The shuttle

Among the satisfying points was the attendance. Indeed, the shuttle transported 847 passengers over the entire operating period (i.e. during the 54 days of operation, Monday to Friday from 11:30 am to 2:30 pm, from Friday, March 1 to Wednesday, May 15, 2019). This figure is relatively more modest than in the first experiment, but it should be put into perspective given the use case that was different. The transported population was also different: during the first experiment, it was mainly tourists. In this second experiment, the people transported were mainly staff from

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local companies, most of whom work in the innovation sector. The effect of curiosity about the technology quickly faded.

The estimated distance (not officially communicated by Navya) corresponds to 1,200 kilometres travelled. The rate of kilometres travelled by the shuttle in autonomous mode is unfortunately not known.

Concerning the drawbacks, one can point out the low maximal speed and the numerous stops of the autonomous shuttle. At this early stage, the shuttle has been set up to behave very carefully. The maximal speed achieved was 18 km/hr, which was quite low and required to adapt the speed limit on the road. The average speed achieved by loop is not communicated also.

Moreover, the shuttle has a limited autonomy since it was unable to overtake any obstacle located on its path by itself. In this kind of situation, the shuttle stopped and required the on-board operator to take control of the vehicle and to drive the shuttle in manual mode. This forced Nantes Métropole to adapt the infrastructure to avoid possible troublesome parking or to prune regularly possible roadside vegetation.

In the on-board logbook, the operators made 347 entries, among which the following events were noted:

- 129 sudden stops of the autonomous shuttle following overtaking by another vehicle;
- 8 problems of vehicles in troublesome parking which led to the resumption of driving in manual mode to bypass the obstacle;
- 73 shuttle stops for no apparent reason;
- Shuttle stops due to heavy rains.

All the on-board operators already had the experience of handling the autonomous shuttle during the first experiment. However, they felt a sense of discomfort during this second open-road experiment, in the following cases:

- Exceeding the shuttle by other users despite the prohibition materialized by the continuous white line and resulting in sudden braking of the shuttle;
- Bad parking of roadside vehicles (quite common in the airport area with trucks in delivery), resulting in the shutdown of the shuttle and resumption of driving in manual mode;
- Vegetation growth on the roadside that could be considered as obstacles by the shuttle and could generate stops upstream.

Navya has provided no other information concerning technical dysfunctions of the shuttle or its equipment, including loss of GNSS signal for instance.

At this stage, no element of costs is available.

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#### 6.3.2.2 The solar road

From the energy point of view, the goal was to produce an average of at least 70 to 80 kWh/m$^2$ per year. This second version of the prototype successfully produced the expected amount of energy, with an observed production of 120 to 130 kWh/m$^2$ per year, even though some remaining electrical problems were encountered. Indeed, only eight out of the twenty-four panels were operating. In addition, the panels withstand to both meteorological and use effects.
Navya has not yet provided the average power consumption of the shuttle but EDF could know it thanks to by looking at the consumption of the container.

#### 6.3.2.3 The infrastructure equipment

The crossing of the intersections did not lead to significant difficulties. The insertion in roundabouts has always been carried out safely. In particular, the communication between the shuttle and the traffic signal controller has been operational.
During the experiment,a group formed by SEMITAN, Navya, Lacroix City and Nantes Métropole reunited every two weeks to discuss about all potential technical problems. This helped a lot to ensure good results for the experiment.

LOGIROAD together with Lacroix City have tested an algorithm to automatically detected passengers at the stations and tried to count passengers going up and down from the shuttle. The automatic counting is based on computer vision and machine learning techniques and required a learning period (a month of data basically). These automatic counts have not been compared yet with the official figures from SEMITAN. However, the lateral angle of vision was not the best possible angle due to potential masks whenever there are several people going up and/or down.

### 6.3.3 Social acceptability

#### 6.3.3.1 Viewpoint of the shuttle users

Cerema addresses this point thanks to a study based on an online survey.

#### 6.3.3.2 Viewpoint of the road users outside of the shuttle

Cerema addresses this point thanks to a study based on an online survey.

#### 6.3.3.3 Viewpoint of the operators

The five operators involved in the manipulation of the shuttle were interview individually at the end of the experiment. It is noteworthy that these operators were selected before the first experiment among voluntary drivers from SEMITAN based on their practical mind, on their years of experience and on their motivation. This selection allowed to ensure the best involvement of the operators during the experiments.
The operators were reassured about the imminence of their work change with the replacement of human drivers by machines. They consider that autonomous shuttles should be more like complementary objects for public transport than a simple direct competitor to current staff members and tools.

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### 6.3.4 Safety

No accidents affecting road safety occurred during this experiment. A more detailed analysis of the conflict situations is carried out by the Cerema, from video recordings by cameras placed at different places of the route, in particular at the crossroads between Halbrane Street and René Mouchotte Street managed by traffic lights, as well as at the roundabout facing the restaurant “RIE”. This complementary analysis aims to distinguish situations of conflicts of use between the shuttle and other road users such as pedestrians, cyclists, light vehicles and trucks driving on the axes of the experiment.

No injuries occurred during the experiment. No falls were recorded. The obligation to sit down and put on a seat belt was confirmed essential because of the abrupt braking of the autonomous shuttle on different occasions (overtaking by another vehicle, presence of roadside vegetation, presence of obstacles and so on).

No material accidents occurred during this experiment.

Navya provided no information regarding potential incidents affecting cybersecurity.

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# 7. Conclusion

It is widely admitted today that the transportation sector is one of the major contributors to greenhouse gas emissions. In order to limit the impact of our behaviour on the environment, it is necessary to propose new solutions enabling a more respectful and sustainable mobility. This is the commitment made by Nantes Métropole on its territory and this is reflected in a strong desire to promote active mobility but also electric mobility. As part of "mySMARTLife" European project, Nantes Métropole decided to deploy the following three actions starting in 2019:

- Replacement of the rolling stock on its high-level service line with 24-meter-long fully electric bi-articulated buses. This deployment was the first one in Europe. This contributes to the transition towards green energy and of-carbon mobility. In addition to their length and increased capacity, these buses have the particularity of being recharged by opportunity during stops at certain stations of the line. This required to install a specific recharging infrastructure and to adapt some stations with longer quays. This operation avoids the need to embark large batteries or to stop the bus for longer recharging times during at the terminals.
- The installation of a network of sixty-five charging stations for electric cars and over two hundreds sockets for electric bicycles as well. The recharging stations for e-cars are mainly deployed in public car parks. This project could be a first step before considering a wider deployment to support a greater development of electric mobility. The evaluation that will be made of the use of these electrical terminals will provide useful feedback for public authorities. There are also issues of payment for the use of these charging stations and on the sizing of the electrical infrastructure to be able to satisfy the demand.
- Experimenting with a fully electric autonomous shuttle that can carry a dozen passengers on a 2.5-kilometer route. This project aims to understand the benefits and limitations of this new mobility technology. After the experiment, it appears that the technology is not yet mature enough to consider an operational integration of this mode in a public transport network. Indeed, the shuttle today has a very careful operation that may lead to many stops. Likewise, its maximum speed of movement is today too low, which causes a nuisance for the other road users. A deeper evaluation carried out by the Cerema is underway and will make it possible to understand the impacts that this shuttle can have in terms of road safety as well as the acceptability of this new mode for the shuttle users and for the other users of the road network.

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